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CURRENT METALLURGICAL ABSTRACTS

VOLUME 3 NUMBER 7

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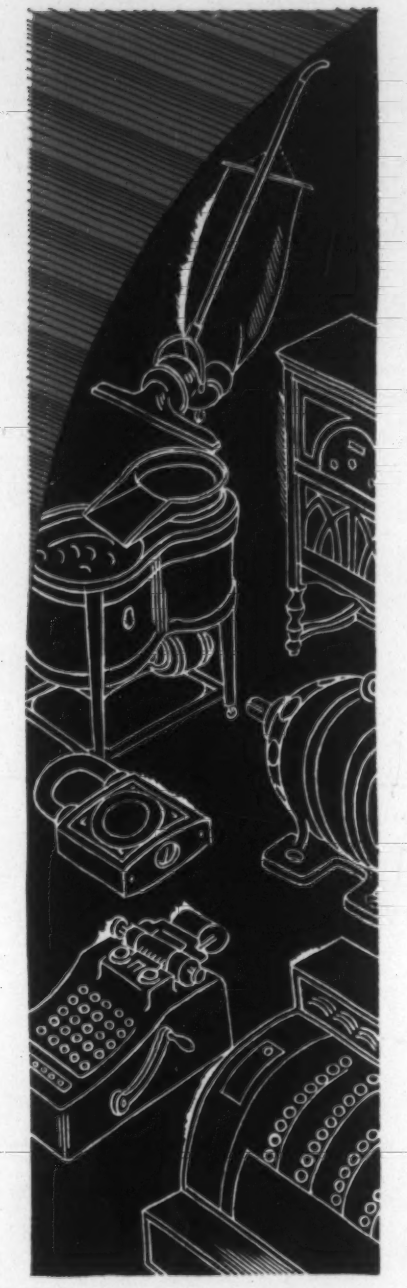

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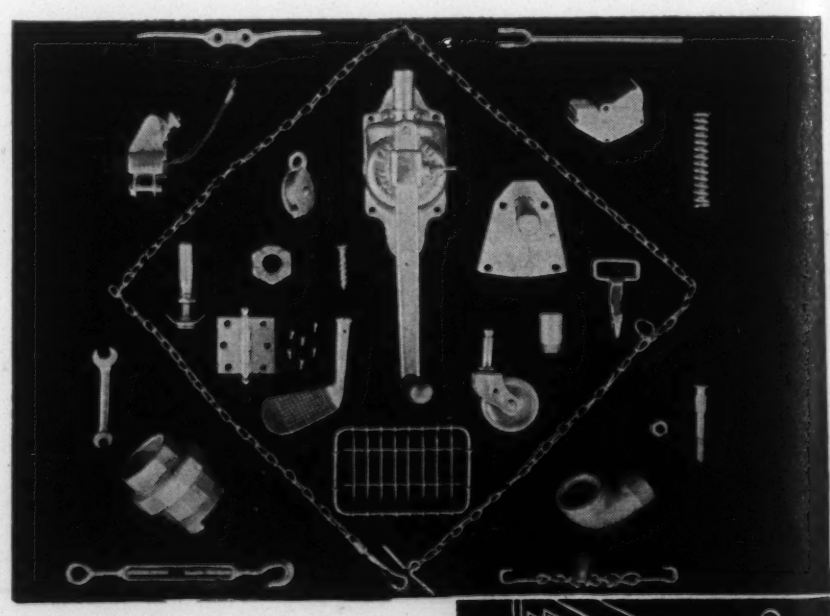

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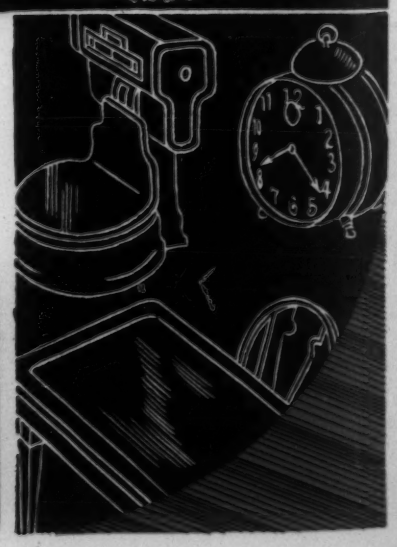

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May 16, 1932

Metals and Alloys
3619 Forbes Street
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Gentlemen:

Your issue of March, this year, contained a very interesting article by Prof. Wilbur E. Harvey. This one article was to me worth the whole price of the year's subscription, and on communicating with Prof. Harvey, asking him some questions about it, he has helped me out so courteously and ably that I wish to thank both you and him for the aid received.

We have recently had a large radial roller bearing destroyed through corrosion. This bearing was so lightly loaded that it should have lasted many years and there was no evidence of any over stress on either races or rollers. The article in your magazine, together with a reprint of an article by Prof. Harvey in April 1930 and taken in connection with his letters of explanation and some photographs which he sent, have been very enlightening.

If you could get the Professor to write you another article showing the photographs and giving the explanations which he gave me in his letters I believe others of your readers would be equally interested.

Yours very truly,

FARREL-BIRMINGHAM COMPANY, INC.

W. A. Gordon

WAG:T

W. A. Gordon
Development Engineer

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EDITORIAL COMMENT

THE ELECTRIC FURNACE and ALLOY STEEL

THE J. W. Richards memorial lecture at the Electrochemical Society meeting in May, by Dr. J. A. Mathews, deserves especial mention, for it is of metallurgical, historical, and human interest. How far we have come in scientific metallurgy is brought out by Dr. Mathews' statement that when he started to institute metallurgical control at the Sanderson Works 30 years ago, carbon content was primarily determined by ingot fracture, the Brinell hardness method had only just been announced abroad, no apparatus being yet available in the United States, there was no pyrometer at the plant, and he assembled and installed the first magnetic testing outfit ever used in a steel works in this country.

In contrast with this, today, "every advance in physics and testing seems to bring about more minutiae, which we attempt to apply to inspection and acceptance tests before we know what it is all about. We seem to suffer from a ferro-gastric disturbance induced by hastily swallowing too many half-baked theories. . . . The only cures are time, experience and learning to say 'I don't know.' A great metallurgist today need not be embarrassed by that admission."

Dr. Mathews comments on the difficulty he had, after studying metallurgy under Sir Roberts-Austen, in finding a connection where the management could see that a metallurgist might be helpful to industry. Nowadays, necessity is as much the mother of research as it is of invention. Research "does not emanate from a spontaneous interest on the part of executives and owners of plants, but from recognized need for improving products or processes or for the development of new products."

An interesting episode cited by Dr. Mathews was the making, at the Halcomb Steel Company in 1909, of good steel from an electric pig iron made for the Canadian Government from ores containing copper and nickel. The steel contained 3.5% Ni and 0.5% Cu, and its good properties did much to dispel the prejudice that had existed against copper in steel. This was the first all-electric heat, both in smelting and melting, made in America. The copper problem was further investigated because of the question of rejection of a carload of spring steel that contained over 0.05% Cu which was prohibited by a specification that had no technical foundation. "Many of the best Swedish wrought irons, from which the leading German, English and American tool steel had been made for generations, contained from traces up to 0.20% Cu."

Dr. Mathews comments on the claims for rival types of electric furnaces, and emphasizes that they are not automatic machines, but require skilled operation. Very good and very bad steel has been produced by crucible, Bessemer, open-hearth and electric processes, according to the skill of the melter.

In the beginning of Dr. Mathews' metallurgical career, there were almost no alloy steels used commercially, save the Mushet tool steels. Taylor and White's modification of the Mushet steel had only just been brought out. Nickel steel and Hadfield manganese steel were known, but for years after, the automobile industry was using carbon steel.

An important step in the development of high speed tool steel was Dr. Mathews' introduction of vanadium in 1903, resulting in the now standard 18-4-1 steel.

The availability of high grade ferro alloys, made by electric smelting; the use of the electric melting furnace in competent hands, and the development of heat treating all combined to make possible the development of many types of alloy steels to meet the needs of the internal combustion motor and the vehicles in which it is used. There are now many alloy steels, which are to a large extent interchangeable.

"It would be a hard matter for many an engineer to give specific reason why he uses chromium nickel steels, while a neighbor uses chromium vanadium and another uses straight nickel steel for the production of somewhat similar parts." "We may say that in the making of many alloys there is no end, and much patenting of them is a weariness to the flesh."

Outside the interchangeable steels, there are some new and original alloys that have resulted from intensive study of their physical characteristics. Among these are cited Honda's magnet steel, Invar, Elinvar, Permalloy, Hadfield's silicon and manganese steels, austenitic stainless steels and the nitriding steels. In the austenitic stainless steels, the addition of Si, Mo, V, etc., so as to retain a little δ-iron, makes for resistance to intergranular corrosion. Many of the properties ascribed to martensite are really due to retained austenite. Hence, neither the austenitic nor the quenched martensitic steels of every-day experience are what they were long supposed to be.

There are other phenomena that are still obscure, which will in time yield to investigation. For example, why should a steel with 2.5 ft.-lbs. impact resistance at 70° F. increase to 165 at 150° F., and why should one heat air harden to 375 Brinell while another of almost identical analysis, fabricated and treated identically, refuse to air harden to more than 325 Brinell?

The whole lecture is very much worth reading.—H. W. GILLETT.

WHITE METAL BEARING ALLOYS

A CORRELATED ABSTRACT by LELAND E GRANT*

PART II. LEAD-BASE BABBITTS

Although the Pb-base babbitts are used extensively at present they have not received nearly as much investigation as the Sn-base alloys and cannot, therefore, be discussed quite as fully. All that was said about the general characteristics of bearing metals in Part I applies, of course, with the same force here and need not be repeated.

Constitutional Diagram

Campbell[40] gives a diagram for the Pb-Sb-Sn system which is similar to that given by Heyn and Bauer[19] reproduced in Fig. 9. Table IX gives the various phases that occur in the fields at the points corresponding to the numbers in the diagram and will be helpful in determining the course of freezing of any of the alloys as well as the type of crystals formed. It is unnecessary to include a detailed discussion of the crystallization of various alloys as only alloys in the area bounded by PbLMO are of particular interest in connection with bearing metals. Three of the 4 principal fields are included in this portion. In the area SbE_2bC the first solid to separate is the solid solution of Sb containing from 0 to 12% tin. This is called δ solid solution. In the area E_2PbE_1dba the first solid to separate is said to be pure Pb, which is especially interesting if true, in view of the fact that Pb will dissolve Sn and such a solid solution of Sn in Pb is one of the secondary phases that separates. In the area CbdH the cubic crystals of SbSn are the first to separate, while in HdE_1Sn α-Sn is the first solid. This carries Sb in solution varying from 0 to 10%. There are, therefore, 4 distinct fields. Point "b," which appears to be a ternary eutectic, is actually a reaction point. There is supposed to be no ternary eutectic in this system as there is no eutectic in the Sn-Sb system. The low thermal points in the system are the eutectic "E_1" (181° C.) "d" (184° C.) and the reaction point "b" (242° C.), while "E_2" is only 245° C.

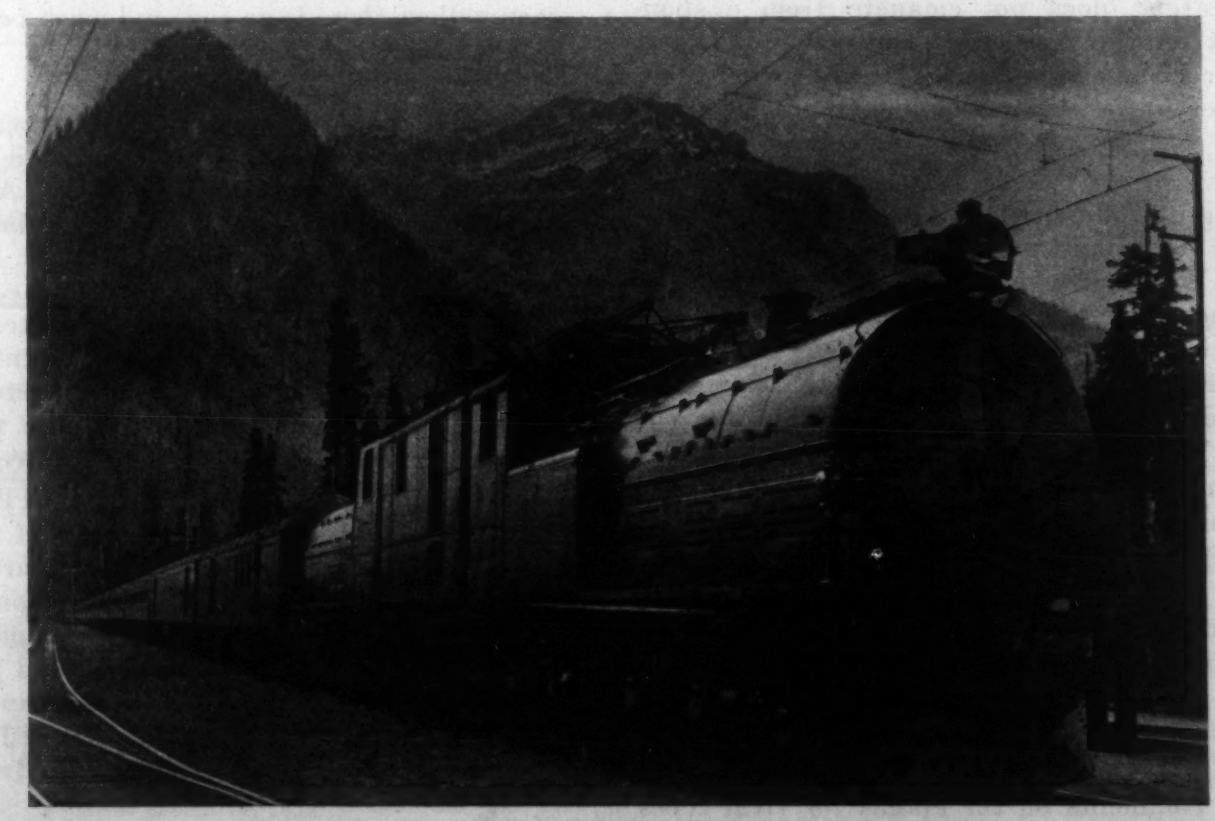
It is interesting to note that the range of 47 to 50% Sn involved in the field BPbC indicates that the ideas discussed in Part I as to the nature of the SbSn cubes apply here equally well, the cubes being a solid solution rather than the compound alone. And, since Sb and Sn are present in substantially equal amounts, some of each are undoubtedly in solution in the compound, though in the cast alloys the quantity will be less than is shown in Fig. 9 as this depicts equilibrium conditions.

Microstructure and Physical Properties

The Pb-base bearing alloys generally contain over 60% Pb, the other 40% being Sn and Sb with a little Cu in certain of the alloys. Additions of Sn increase the hardness and rigidity without increasing the brittleness. Sb additions increase the hardness but also the brittleness so that this element seldom exceeds 25% for this reason and most of the practical alloys contain not over 15%. Cubes of SbSn tend to increase the coarseness of the structure. Although the hardest alloy of the system is at 60% Sb, 30% Sn, and 10% Pb with a Brinell hardness of about 78 it, of course, lies outside of the useful bearing metal range because of its brittleness. The general components of the solid alloys in any of the vari-

*Chief Chemist, Chicago, Milwaukee, St. Paul & Pacific Railroad Company.

Editor's note: Part I appeared in the June issue.



The Olympian—famous transcontinental train of the Milwaukee Road—electrically operated over four mountain ranges.

Table IX. Structural Constituents of Various Fields of Fig. 9

Field	Boundary	Phases	End of Freezing	Temperature
1	Pb X B Pb	δ, Pb + δ, Pb + β	b	242° C.
2	"	δ + β, Pb + β	b	242° C.
3	"	Pb + β	b	242° C.
8	"	Pb, Pb + δ, Pb + β	b	242° C.
5	Pb Sb X Pb	δ, Pb + β	Between E_2 and b	
14	"	Pb, Pb + δ	" " " "	
4	Pb BC Pb	β, Pb + β	Between b and d	
15	"	" "	" " " "	
16	"	Pb, Pb + β	" " " "	
6	PbC G Pb	β, Pb + β, Pb + α	d	
7	"	β + α, Pb + α	"	
9	"	Pb, Pb + β, Pb + α	"	
11	Pb G Sn Pb	γ + α,	Between d and E.	
12		α, γ + α		
18		" " "		
13		" " "		
10		γ, γ + α		
17		" " "		

δ = Sb with 0 — 12% Sn in solid solution.
β = SbSn solid solution containing 47 — 50% Sn. Range BC.
α = Solid solution of tin containing 0 — 10% Sb.
γ = Solid solution of lead containing 0 — 18% Sn. (Probably requires revision to comply with present conception of the Pb-Sn system.)
Underlined groups are pseudo-eutectics.

ous fields can be determined from Table IX and Fig. 9 so no attempt will be made to discuss the appearance of each type of alloy under the microscope. The various constituents can in general be recognized by their characteristics. The cubes of SbSn appear the same as in the Sn-base babbitts. The δ crystals when present as a separate phase are lighter in tone, tend to be more massive, and are more elongated than SbSn crystals. They have, however, the same sharp boundaries. The Pb and Pb-Sn (γ) crystals cannot be distinguished from each other and both will be found as rounded grains frequently without any sharp boundary line. In rapidly cooled alloys the δ and β crystals are always smaller than in the slowly cooled alloys. The 4 eutectics usually cannot be differentiated by appearance and the eutectic structures of Pb + α and Pb + β nearly always appear to be less distinct in the rapidly cooled alloys than in those slowly cooled. Annealing for 130 hours at 150° C. favors attainment of complete equilibrium and better differentiation of the various constituents.

Cast alloys will of course not have all of the struc-

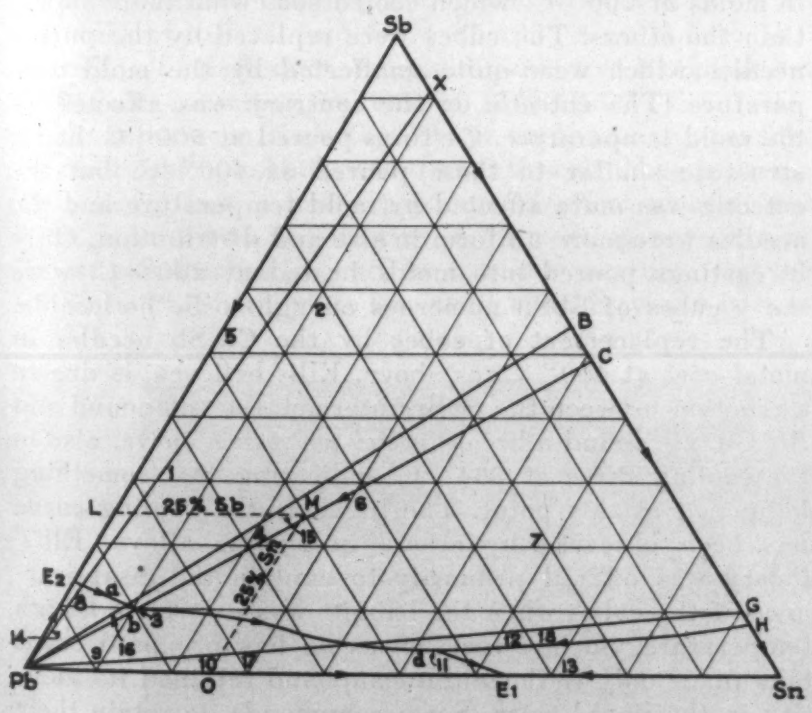
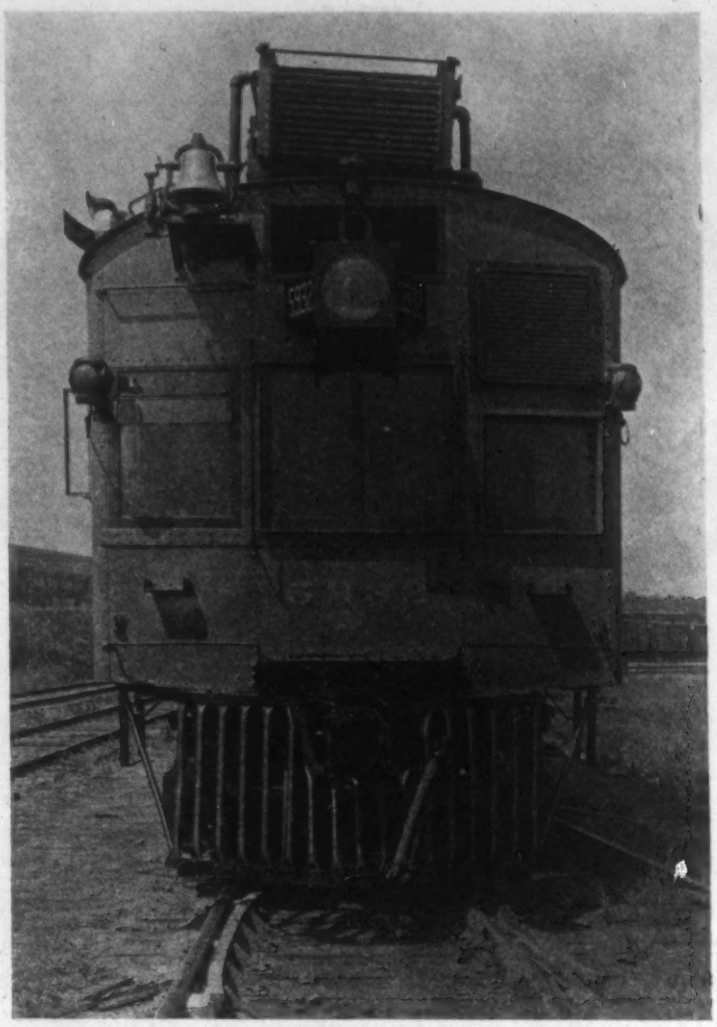


Fig. 9. Lead-Tin-Antimony Equilibrium Diagram

Point	%Tin	%Antimony	Solidification Point C°.
E_1	64	0	181
E_2	0	13	245
b	10	10	242
d	53.5	4	184
C	50	50	420
H	92	8	243



Gas-electric Car—Motor End.

tures indicated in Table IX because the comparatively rapid cooling prevents the reactions from going to completion. This fact necessarily has a bearing on the performance of the metal in service. The γ solid solution of Sn in Pb must be affected markedly by rapid cooling because of the strong curvature of the solvus line in the binary system of these 2 metals. The annealing effect from operation of the bearing at somewhat elevated temperatures must cause precipitation of some of the Sn with consequent softening of the alloy. The other solid solutions have comparatively straight solvus curves and consequently it is not to be expected that they would be affected to the same degree. It is unfortunate that an alloy of this type was not included in the work of Freeman and Woodward.[28] This feature and the possible lowering of the melting point due to "pick-up" of Sn from the solder used in tinning the back undoubtedly have a bearing on the serviceability of the metal. It is common practice for some firms to use an 80-20 solder instead of 50-50 for tinning the back as it produces a good bond for the high lead linings and is cheaper in cost.

Referring to Fig. 9 it will be found that the practical bearing metals lie in the area bounded by PbLMO and the primary crystals may be Pb, γ, β, or δ. Considerable variation in microstructure and properties is, therefore, to be expected in these alloys. The hardness of rapidly cooled ingots, the composition of which lie in this area, varies from a Brinell number of 5 for the nearly 100% Pb to 35 for the alloy containing 25% each of Sn and Sb. There is a decrease from this value to only 25 Brinell for alloys containing 12% Sb, and 10% Sn. This is close to point "b" in Fig. 9. All of the alloys in this region containing over about 5% Sb show a decrease in hardness if the quickly cooled alloy is annealed at 150° C. Slow cooling also causes softening. Curves for impact strength similar to those for hard-

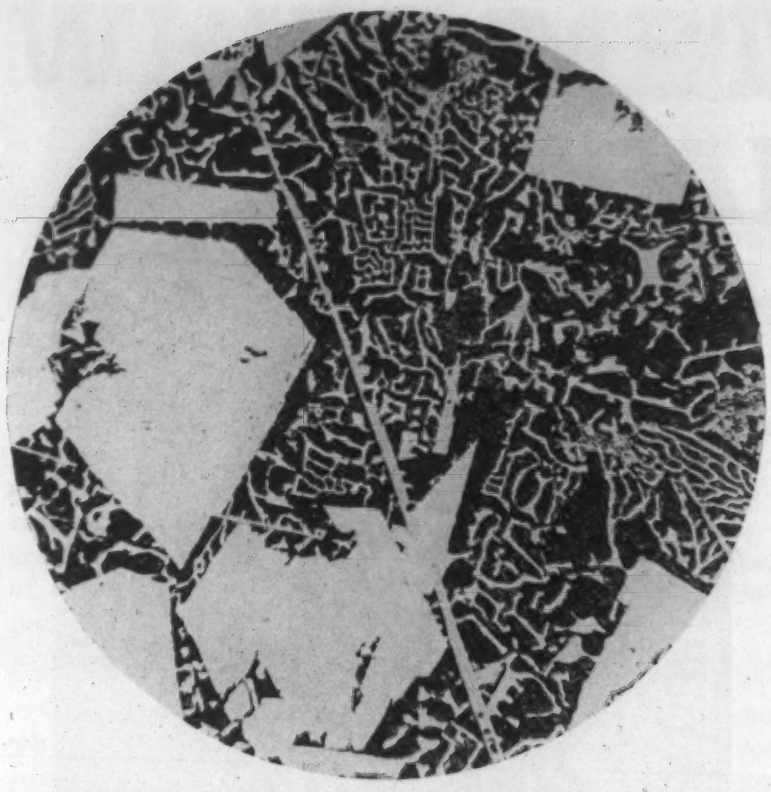


Fig. 10. Regulus of Venus needles in a lead-base Babbitt. As 0.02%, Sb 14.91%, Sn 11.97%, Pb 72.26%, Cu 0.66%. Brinell 23.2. 100X.

ness, with the impact strength increasing with hardness. Curves showing the load required to cause a 2% diminution in height of test pieces are, of course, very similar. At point "b" this compression load is approximately 850 kg./cm.^{2}. (12,000 lbs./in.^{2}). The brittleness increases rapidly with the hardness but the Sn rich alloys with less than 25% Sb are an exception. Even though they have high hardness values they are strong under impact. These alloys, however, do not form an exception under compression tests where the load is applied slowly. The variations in hardness of these alloys are interesting since they are an example of an increase in hardness brought about by the addition of a soft metal. The addition of soft Sn to Pb-Sb alloys raises the hardness; and similarly the addition of Pb to Sb-Sn raises the hardness.

Segregation is a serious defect in some of these alloys. The cubes of SbSn are specifically lighter than the Pb-rich liquid and tend to rise. The segregation, therefore, increases with the Sn. It becomes maximum at a moderate amount of Sn and then decreases with increasing Sn content. Alloys in field 6 of Fig. 9 in particular show segregation. This can be controlled somewhat by rapid cooling but, as this also has a marked effect not only on the size and shape of the crystals but also on the physical properties, the casting conditions must be controlled closely. Heyn and Bauer recommend that cooling be as rapid as possible during the solidification interval but Rolfe[45] says that too rapid cooling produces too fine a structure, the alloy becoming practically homogeneous. It seems doubtful, however, if any practical cooling conditions such as would be available in the shop are likely to produce too fine a structure in these alloys.

Ellis[41] made an extensive study of the effect of casting conditions on the structure. The alloy used in most of his experiments, 83.1 Pb, 12.1 Sb, 4.8 Sn, was signally affected by the conditions associated with pouring. Samples were poured at 50° C. intervals between 300° and 500° into iron molds at temperatures from 0° to 200° C. He found that for a given mold temperature an increase in pouring temperature increased the size of the cubes as well as causing a general coarsening of the matrix. An attempt to correlate the size of the cubes or coarseness of the matrix with cooling times was not completely successful. The alloy poured at 500° into a mold at 0° cooled quicker than the alloy poured at 300° into a mold at 100° but had the larger cubes. This may possibly have been due to undercooling but is in agreement with the work of Hudson and Darley[11] on the Sn-base babbitts. An increase in pouring temperature had less effect on segregation than did an increase in mold temperature. Marked segregation occurred only in the case of the highest mold temperature. An increase in mold temperature reduced the resistance to slowly applied stress, as reported by Heyn and Bauer.[19] Variation in mold temperature had more effect on hardness than did variation in pouring temperature.

In order to overcome the segregation, especially in large bearings, Cu has been introduced up to about 6%. Heyn and Bauer[19] investigated the effect of Cu and found the arrest points in the cooling curve were only slightly displaced but a new upper arrest at 618° C. was observed corresponding to the separation of needles of a Cu compound and the beginning of solidification. The solidification interval is extended by the Cu, becoming greater the higher the Pb content. Final solidification is, of course, the same. With only 3 to 4% Cu the segregation is eliminated but it is not known if this much Cu changes the point of initial freezing. Ellis[41] studied the effect of 1% Cu in an alloy of 82.5 Pb, 11.0 Sb, and 5.5 Sn. Alloys were cast at the same temperature of mold and metal as given in his work above. Only micrographic examination was made and the results were rather surprising. The 1% Cu completely eliminated the segregation, not by entanglement of the cubes by needles of a Cu-Sn compound as in the case of some other Pb-base babbitts, but in castings poured at 300° C. by an effect as yet undetermined; and in castings poured at 400° to 500° by a complete change in structure. The cubes were replaced by purple needles of the compound Cu_2Sb (Regulus of Venus). In castings poured at 300° C. the cubes became larger and the matrix coarser with increase in mold temperature. Needles of Cu_2Sb were not entirely absent but were relatively few in number. In castings poured at 400° C. but few cubes were found; in fact, they were rare except in castings poured in molds at 200° C. which cooled somewhat more slowly than the others. The cubes were replaced by the purple needles which were quite unaffected by the mold temperature. The eutectic on the contrary was affected by the mold temperature. Castings poured at 500° C. had a structure similar to those poured at 400° C. but the eutectic was more affected by mold temperature and the needles were more uniform in size and distribution. Only in castings poured into molds heated at 200° C. were the γ cubes of SbSn numerous enough to be noticeable.

The replacement of cubes by the Cu_2Sb needles in metal cast at 400° C. or above, Ellis believes, is due to a reaction between the SbSn intermetallic compound and the Cu. He found a break in the resistance curve, also in the cooling curve at 334° C. indicating that something happened at this point. The break in the cooling curve has been observed by others in similar alloys. Ellis' theory was offered primarily to explain the disappearance of the cubes when the babbitt was cast from a high temperature. Such a reaction as he has proposed could take place only if the SbSn compound retained its identity in the liquid state. Some compounds do retain their identity but X-ray evidence indicates it to be an uncommon occurrence. Bornemann[46] however, has presented evidence that the compound Cu_2Sb does exist in the liquid. Further evidence as to the manner of formation of the Cu_2Sb seems to be required. X-ray examination

would undoubtedly reveal whether the SbSn compound exists in the liquid and if the Cu-Sb intermetallic compound is formed at 334°C. It is an interesting problem for research. In fact a complete study of the effect of Cu in this system is needed, the available information being very meager. Fig. 10 shows the needles of Regulus of Venus in a Pb-base babbitt with only 0.66% Cu. The diametrical needle is very conspicuous. It is interesting to speculate as to why these same needles are not observed in Sn-base babbitts where Cu and Sb are present in somewhat similar proportions.

Since but little Cu is involved with the Sb to form needles in the alloys as cast into bearings, it seems probable that the Cu has some additional effect. This is to some extent borne out by the fact that sometimes, when both the cubes and needles are found, the cubes have a weblike structure or non-homogeneous centers as if the Cu had affected them. As shown in Part I Cu may be dissolved by the cubes of SbSn to the extent of around 5% and it may be this solution of Cu that gives them the weblike appearance. It appears that further investigation of the effect of Cu is necessary before any definite conclusions are to be drawn.

Bismuth

The effect of impurities on these alloys has not been investigated so extensively as in the case of the Sn-base bearing metals. It has been stated that the addition of 0.2% Bi to the Pb-base alloys reduced the frictional resistance over one-half,[48] but this was increased by addition of more Bi. (A minute quantity of an impurity reduces friction if the atomic volume of the impurity is greater than that of the alloy, the converse also being true.) As to the effect of Bi on the other properties of the babbitt no information was found. It has sometimes been added to Magnolia metal.

Arsenic

The effect of As, small amounts of which are practically always present in these alloys, has been investigated but little. Some work on the effects of As and Zn in Pb-base alloys was done by Freeman and Brandt[35] at the Bureau of Standards. They found additions of As up to 0.46% to an alloy of 73.8 Pb, 16.7 Sb, 9.3 Sn caused an increase in hardness of about 7% (22 to 23.5 Brinell) at 20° C. and 13% at 100° C. (11.5 to 13.0 Brinell). The effect on the yield point was irregular but 0.46% As caused an increase of 15% at 20° C.

No reports on the effect of As on the microstructure of the Pb-base babbitts was found though there is reason to believe that it has a pronounced effect since it has been reported to be effective in preventing segregation. Roast and Pascoe[49] found As to cause the cubic crystals of Sb in Pb-Sb alloys to lose their symmetry and become

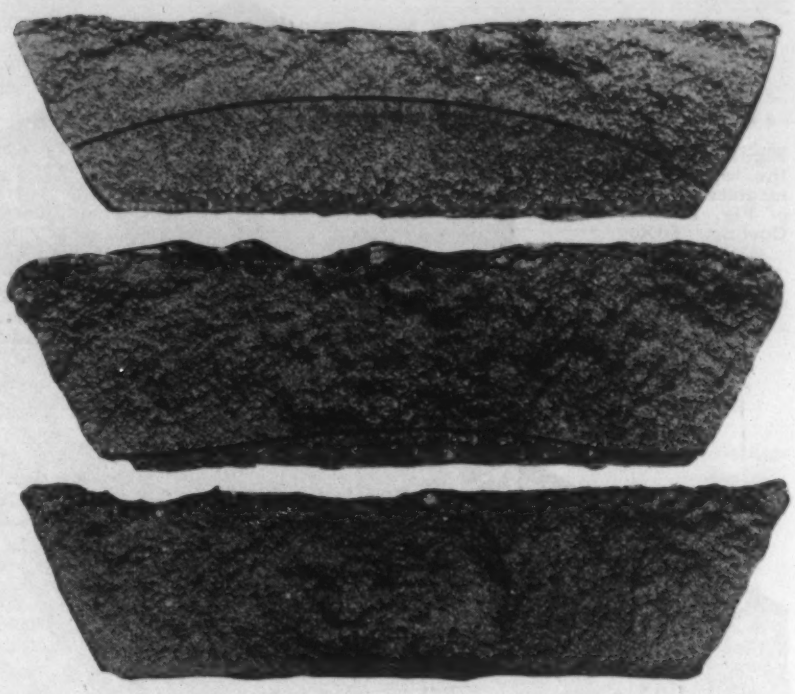


Fig. 11. Ingots of Lead Base Babbitt with Varying Arsenic Content Showing a Decrease in Segregation with Increasing Arsenic. About 2X. No. 1 at top, No. 2 in center, No. 3 at bottom.

somewhat curved. The Sb also came out in smaller units thus producing a grain refinement. They did not investigate the effect of As on Pb, Sn, Sb alloys. Some research work in the author's[55] laboratory has shown that even 0.5% As has a pronounced effect on the microstructure as well as on segregation. Fig. 11 shows 3 ingots, about twice actual size, which were permitted to cool in the atmosphere in sheet iron crucibles. The previously prepared alloys were simply heated to about 425° C. to melt them and the crucibles were then left to cool. Ingots 1 and 2 show segregation, the extent of which is indicated by the line on the photograph. Ingot 3 did not show macroscopically visible segregation. Analyses of metal taken close to the top and bottom surfaces of these ingots were as shown in Table X.

This shows very clearly that As is effective in preventing segregation. In ingot 2 the As rose to the top of the melt with the Sb and Sn. Fig. 12 is a composite micrograph showing the various structures in ingot 1.

Table X. Analysis of Ingots Used in the Study of the Effect of Arsenic on the Microstructure of a Lead Base Babbitt

	No. 1		No. 2		No. 3	
Ingot	Top	Bottom	Top	Bottom	Top	Bottom
Arsenic	0.08%	0.03%	0.54%	0.08%	1.53%	1.35%
Antimony	16.94%	10.72%	14.81%	11.08%	14.62%	14.84%
Tin	12.71%	8.41%	10.80%	7.49%	10.62%	10.44%
Lead (diff.)	70.27%	80.84%	73.85%	81.35%	73.23%	73.37%
Brinell No.	31.2	22.8	25.9	22.8	31.2	28.4

Fig. 12. Composite Micrograph of Structure in Top Ingot of Fig. 11. 100X.

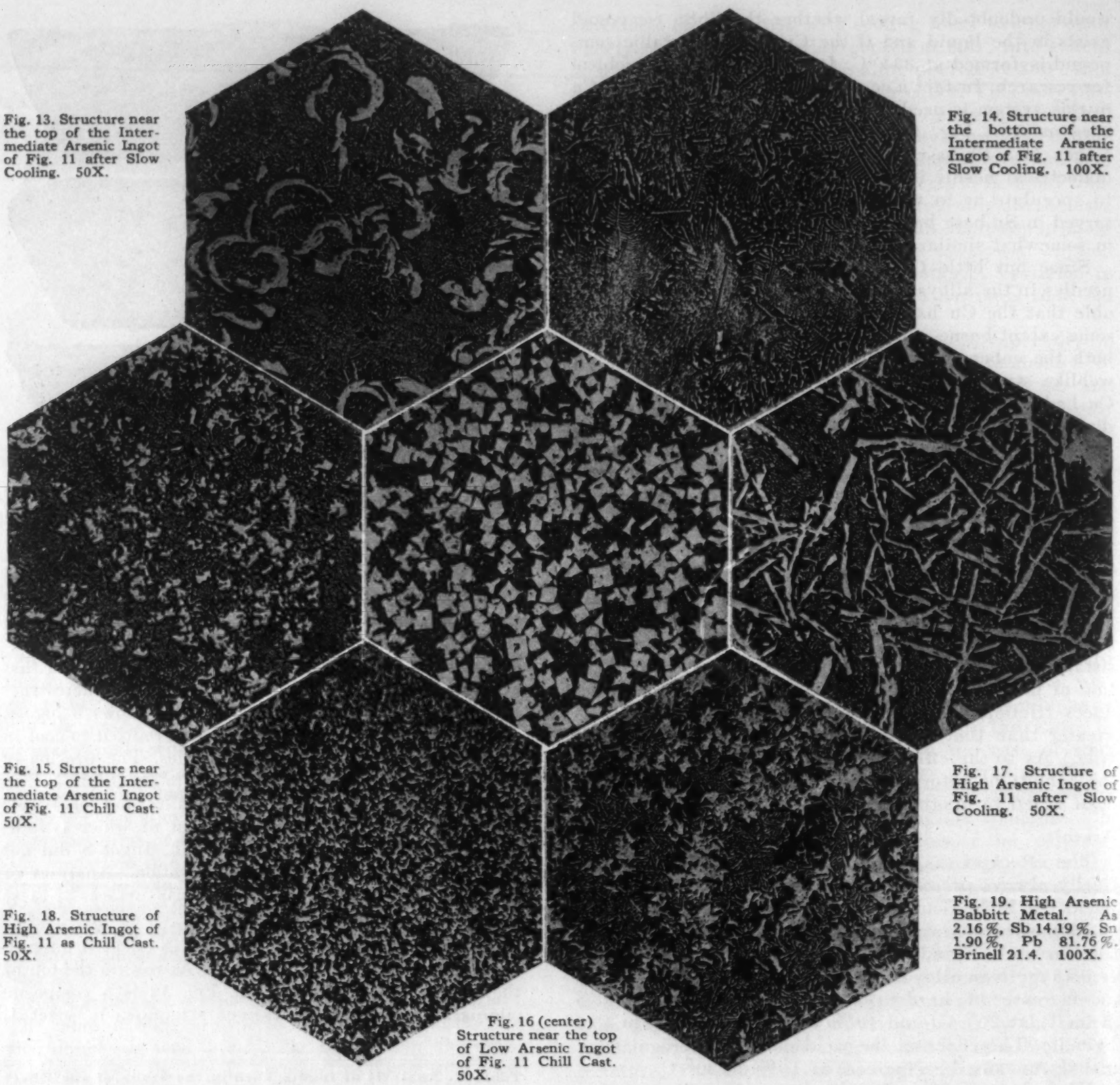


Fig. 13. Structure near the top of the Intermediate Arsenic Ingot of Fig. 11 after Slow Cooling. 50X.

Fig. 14. Structure near the bottom of the Intermediate Arsenic Ingot of Fig. 11 after Slow Cooling. 100X.

Fig. 15. Structure near the top of the Intermediate Arsenic Ingot of Fig. 11 Chill Cast. 50X.

Fig. 17. Structure of High Arsenic Ingot of Fig. 11 after Slow Cooling. 50X.

Fig. 18. Structure of High Arsenic Ingot of Fig. 11 as Chill Cast. 50X.

Fig. 19. High Arsenic Babbitt Metal. As 2.16%, Sb 14.19%, Sn 1.90%, Pb 81.76%. Brinell 21.4. 100X.

Fig. 16 (center) Structure near the top of Low Arsenic Ingot of Fig. 11 Chill Cast. 50X.

Figs. 13 and 14 show the top and bottom respectively of ingot 2. The magnification is only 50 diameters in these and several of the following micrographs. The effect of the As in changing the cubic SbSn crystals to a curved shape is pronounced, the effect being similar to that observed by Roast and Pascoe in their Pb-Sb alloys. Fig. 15 shows the top of another ingot of the same composition as No. 2 but chill cast and Fig. 16 shows the top of a chill cast ingot of the composition of ingot 1. Comparison of Figs. 15 and 16 shows that the arsenic has caused grain refinement and destroyed the symmetry of the cubic crystals. Fig. 17 of ingot 3, slowly cooled, shows a progression of the effect of the arsenic. The curving of the original cubic crystals has now almost disappeared and rod like crystals are found instead. There was no definite difference in appearance between the top and bottom of this ingot. Fig. 18 shows the structure of a chill cast ingot of the composition of No. 3. There is greater grain refinement than shown in ingot 2, as chill cast, and the tendency to cubic crystallization has now practically disappeared.

These experiments indicate that arsenic causes grain refinement in the Pb-base babbitts, tends to overcome segregation, and interferes with the cubic crystallization of the Sb-Sn solid solution. The changing crystal form of the solid solution SbSn and the tendency of the As to rise to the top of the melt can be explained on the basis of solution of the As in the cubic crystals. An appreciable increase in hardness accompanies the grain refinement. Arsenic is, therefore, to be considered beneficial in some respects but unfortunately it confers some undesirable properties to the metal that offset its advantages. It was pointed out in the discussion of the paper by Roast and Pascoe that in practice a high As content interfered with the proper adhesion of the babbitt lining to the backing. Loose linings will almost inevitably fail in service and As must, therefore, be looked on with suspicion at least in this grade of babbitt, if it exceeds the usual limits of about 0.25%. Nevertheless, high As babbitts are commercially available and Fig. 19 shows the structure of a commercial ingot containing over 2.0% As. The grain is fine and the hardness higher than nor-

mal for babbitt of similar composition without As. High As babbitts are said to lack toughness but no report of experiments made to prove this were found in the literature. The relatively high Brinell hardness does not necessarily connote any marked decrease in toughness.

Zinc and Copper

Zinc[35] up to 1.4% raised the hardness and yield point similar to As but 1.4% Zn raised the yield point at 100° C. some 20%. Additions of Cu up to 1.1% produced effects on the physical properties similar to those of As. It is effective in minimizing segregation but raises the pouring temperature as a few tenths % will cause frothing if the alloy is poured below 482° C.[50] Copper is ordinarily not present as an impurity to an extent that it would affect the properties significantly.

Tin and Antimony

Considering now some of the more general features of these alloys it will be found that the replacement of Pb by Sb[2] increases the resistance to compression and increases the hardness. Antimony-rich alloys, which require a much higher temperature for fusion, sometimes show considerable quantities of stannic oxide crystals (SnO_2). The deterioration of bearing metals in service when overheating takes place, may possibly be traceable to the formation of these hard crystals. Remelting of high Sb alloys is likely to cause a loss of Sb and a decrease in anti-friction quality. Replacing the Pb by Sn improves the properties as it increases the rigidity and hardness without increasing the brittleness. Increasing the quantity of cubes tends to coarsen the general structure and render the alloys brittle and weak.

The physical properties of the A.S.T.M. Pb-base bearing metals are shown in Table XI.

The physical properties of the Pb-base alloys are inferior to those of the Sn-base group. The Pb-base alloys have a compressive strength of 13,000 to 15,000 lbs./in.^{2} with a Brinell hardness of 15 to 20 while the Sn alloys as a class have an equal or higher compressive strength and a higher Brinell hardness. But elastic limit in compression is 2 or 3 times as high in the Sn-base as in the Pb-base alloys. However, owing to the high price of Sn, it is often more economical to use a larger bearing of Pb-base metal. But when lightness and strength are essential the Pb-base bearing metals will not receive much consideration.

The rate of wear of Pb-base alloys is less than that of the Sn-base,[47] but the heat developed is not dissipated so rapidly. For this reason they are not so well adapted to high speeds where rapid dissipation of heat is essential. The shrinkage[47] is about the same for both types amounting to 0.6%. The ductility of Pb-base alloys is somewhat greater as, comparing common compositions of each type, one finds that in a Pb-base alloy cylinders can be compressed 46% before cracking while the Sn-base will stand only 33%. The yield point of the Pb base alloys is lowered considerably by prolonged heating at 100° C. while the Sn-base alloys are not affected by the same treatment.

Although both types begin to melt at very nearly the same temperature the Sn alloys have to be poured at 100° to 150° C. higher, at least for thin linings, because of the rapid loss in fluidity as the temperature falls. The pouring temperatures are about 325° to 350° C. for the Pb-base alloys, and 425° to 500° C. for the Sn-base alloys. Table XIV presents the solidification intervals of a number of the ternary Pb-base alloys. If Cu is used in Pb alloys containing less than 10% Sn the pouring temperature has to be raised to prevent frothing[51] but as these alloys have only a slight tendency to segregate it appears better to avoid Cu in this range as is done in the A.S.T.M. standard bearing metals.

Table XI. Physical Properties of A.S.T.M. Lead Base Babbitts

No.	Sn	Sb	Pb	Cu	Pouring Temp. °C.	Ultimate Strength lbs./in.^{2}	Brinell No. 20°C.	Brinell No. 100°C.
1	20	15	63.5	—	346	14450	21	10.5
2	10	15	75	0.5 max.	338	15650	22.5	10.5
3	5	15	80	0.5 max.	341	15600	20	9.5
4	5	10	85	0.5 max.	327	14700	19	8.5
5	2	15	83	0.5 max.	332	15450	17.5	9.0

Table XII. Composition of the S.A.E. Lead Base Babbitts

	No. 13	No. 14
Tin	4.50 to 5.50%	9.25 to 10.75%
Antimony	9.25 to 10.75%	14.00 to 16.00%
Lead maximum	86.0%	76.0%
Copper	0.50%	0.50%
Arsenic	0.20%	0.20%
Zinc and aluminum	none	none

Table XIII. A.R.A. Specification for Journal Bearing Linings

	Specification %	Average Composition %
Tin	As Specified	4.0
Antimony minimum	8.0	9.0
Tin and antimony	10 to 14	13.0
Arsenic maximum	0.20	0.14
Copper maximum	0.50	.....
Sum of tin, lead, antimony, and arsenic minimum	99.25	.....

Table XIV. Solidification Intervals of Ternary Lead-Base Bearing Metals

Composition %			Solidification °C.	
Lead	Tin	Antimony	Beginning	End
90.0	2.0	8.0	268	242
85.0	5.0	10.0	250	242
70.0	20.0	10.0	234	184
80.0	5.0	15.0	269	242
80.0	10.0	10.0	242	242
70.0	15.0	15.0	261	184
71.0	5.0	24.0	325	242
75.0	10.0	15.0	265	242
60.0	20.0	20.0	297	184
70.0	10.0	20.0	289	242
50.0	40.0	10.0	241	184

Applications

From what has been said about the physical properties it is clear that the Pb-base alloys will be used where the requirements for strength and resistance to impact are not the highest or, if they are high, conditions are such as to permit the use of generous sized bearings. For many slow speed and moderately heavy load conditions these alloys are very satisfactory. When supported by an adequate backing they also meet rather severe conditions equally well. They have been used extensively for car journals here and abroad. The well known Magnolia metal belongs in this class. Many of the modern machines as well as line shafts and electric motors are equipped with the Pb-base bearings. Allen[52] has the following to say in regard to the application of bearing metals: For general heavy duty service a Pb-base metal is suitable; for extra heavy duty as for example light type crushers, cement mills, etc., a semi-Sn metal containing Cu may be used; for extreme speed and heavy duty service or for bearings subject to shocks and vibration a Sn-base alloy should be used.

A.S.T.M. Alloy No. 6 Table XI, but with 1.5% Cu in addition, has been successfully used in England for railroad service in applications where it is not subject to changes in stress.[53]

The S.A.E. Pb-base bearing metals are 2 in number the composition of which are essentially the same as the A.S.T.M. No.'s 9 and 7 respectively. The compositions are given in Table XII. These are cheap babbitts used successfully where the bearings are large and the service light.

The A.R.A. specification and average composition of the linings for journal bearings are as shown in Table XIII.

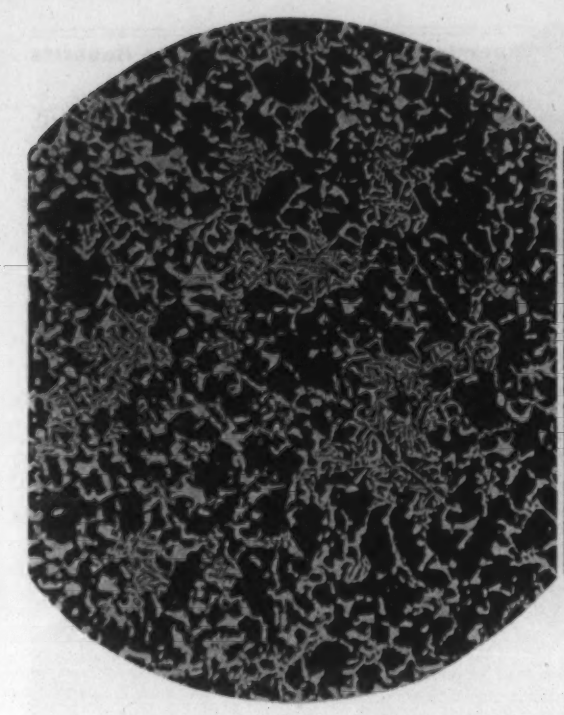


Fig. 20. A.R.A. Car Journal Lining Metal. Poured at 650 F. As 0.41%, Sb 9.27%, Sn 5.00%, Pb 85.32%. Brinell 17.8. 100X.

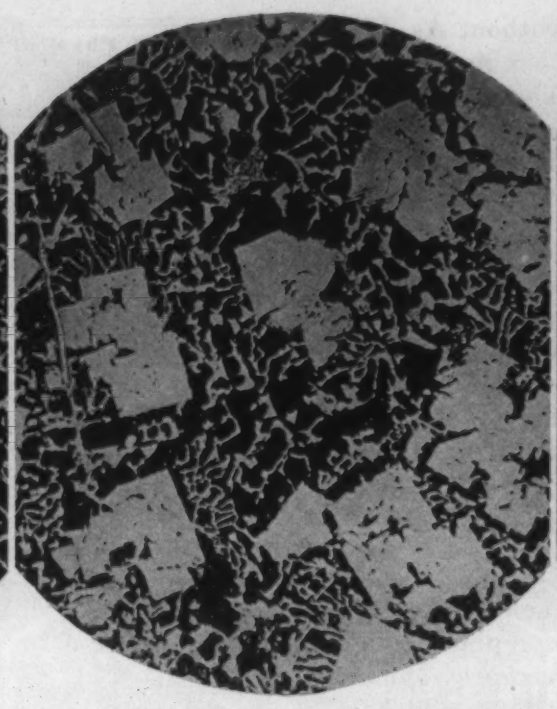


Fig. 21. Babbitt for Locomotive Crosshead Shoes. As 0.20%, Sb 14.91%, Sn 19.15%, Pb 64.87%, Cu 0.87%. Brinell 22.8.

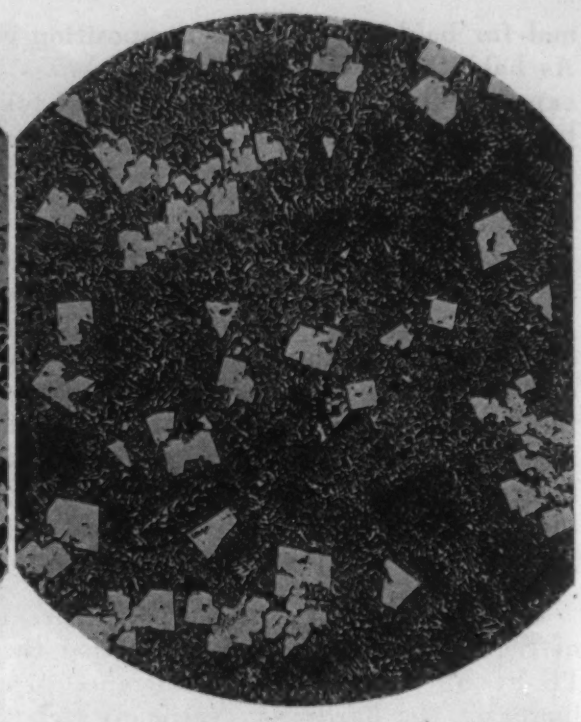


Fig. 22. Babbitt for Locomotive Truck Journals. As 0.12%, Sb 14.23%, Sn 8.77%, Pb 76.88%. Brinell 21.8. 100X.

Fig. 20 shows the appearance of such metal as cast for a car bearing. This is a very satisfactory lining for car bearings and it is rare, indeed, for a properly made lining to be the source of any trouble. The bearings operate under high static loads (400 lbs./in.^{2} of projected area) and severe shock loads with poor lubrication and not infrequently are poorly fitted at the start. Nevertheless they go on giving miles of trouble free service until worn out. A.S.T.M. alloy 2, shown in Fig. 22, is used in lining locomotive trailer bearings.

The A.S.T.M. No. 6 babbitt has frequently been used for filling the grooves in locomotive crossheads in the belief that a hard babbitt was necessary. In service the babbitt very quickly wears down below the cast iron of the crosshead shoe and the grooves become oil reservoirs for all practical purposes. More recent practice has been to use car journal babbitt as described above with considerable saving over the cost of the 20% tin babbitt. In some shops the babbitt melted out of scrapped car bearings is used for this purpose with entirely satisfactory results and considerable economy.

ACKNOWLEDGMENTS

The author desires to thank the American Society for Steel Treating for the use of the drawing for Fig. 1. He is indebted to various members of the "Milwaukee Road" Test Department for assistance in the work and especially to K. H. Wegner for making the many analyses. R. E. Bultman very kindly furnished the sample of centrifugally cast babbitt from which Fig. 6 was made.

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Lt. Commander Homer N. Wallin and **Lt. Henry A. Schade**, U. S. N., at Mare Island Navy Yard, winners of $7,500 first prize in Second Lincoln Arc Welding Prize Competition.

◈ ◈ ◈

William S. Wilbraham, who has been in charge of the Estimating and Order Department at Lukenweld, Inc., Coatesville, Pa., since this organization was established in 1929 to manufacture welded parts for machinery and equipment, has been appointed Assistant Manager of Sales. Mr. Wilbraham is a graduate in Mechanical Engineering, Drexel Institute, class of 1925. He was connected with the American Bridge Company as Assistant Engineer of Erection on the Camden end of the Delaware River bridge until March, 1927, when he joined the sales department of Lukens Steel Company.

◈ ◈ ◈

The Machine Shop Practice Division of the American Society of Mechanical Engineers under the chairmanship of F. C. Spencer of the Western Electric Company at Kearny, N. J., have voted unanimously to transfer the program which they had previously planned to hold at the Machine Tool Show in Cleveland to the National Metal Congress at Buffalo, the week of October 3.

In addition to the Machine Shop Practice sessions of the A.S.M.E. the program which had been planned by the Society of Automotive Engineers to be held in Cleveland, has also been transferred to Buffalo.

Invar, Elinvar and Related Iron-Nickel Alloys†

By J. W. SANDS*

PART II

THE data presented up to this point may be taken as fairly representative of the performance which may be expected from ordinary commercial alloys in the natural or annealed condition. However the low expansion properties of these alloys are adversely affected to a material extent by various extraneous elements ordinarily present in steel, such as carbon, manganese and silicon. Tests by Scott on a 45% nickel steel indicate that 1% manganese raises the coefficient of expansion by 0.26×10^{-6} per °C. (0.14×10^{-6} per °F.), and lowers the inflection temperature 20°C. (36°F.). One percent silicon lowers the inflection temperature 30°C. (54°F.) but appears to be without effect on the expansion coefficient. The effect of various third constituents upon the alloy of minimum expansion has been studied very thoroughly by Guillaume. He found that the nickel content necessary for minimum expansibility varies in the presence of carbon, manganese, copper or chromium to the extent shown in Fig. 12. That is to say, the point of minimum expansibility shown in Fig. 1 (36% nickel) is shifted to the right by manganese and chromium and

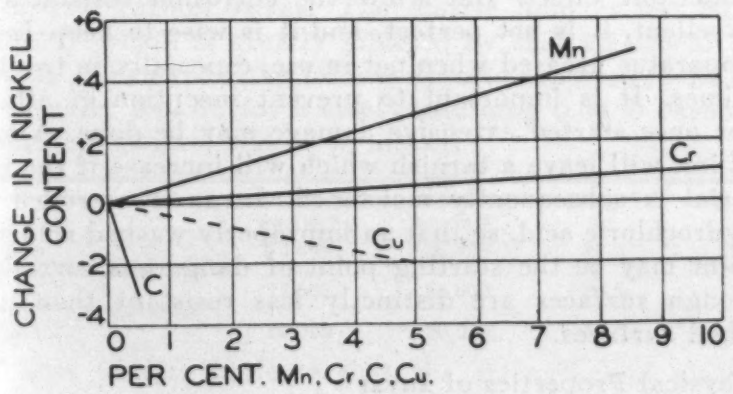

Fig. 12. Changes in nickel content necessary for minimum expansibility in the presence of various third constituents (Guillaume)

to the left by copper and carbon to the extent indicated in Fig. 12. Furthermore, the minimum point is raised by the presence of these elements to the extent shown in Fig. 13. In the presence of 2% of manganese, for example, the lowest possible expansivity will be secured when the nickel content is slightly over 37% instead of 36% and the value of the minimum coefficient of expansion will be approximately 2.5×10^{-6} per °C. (1.4×10^{-6} per °F.) higher than that corresponding to the pure 36% nickel-iron alloy.

From the standpoint of optimum nickel content, carbon and manganese tend to balance one another so that in specifying nickel content for commercial Invar it is probably not advisable to depart from the customary 36%. However, Fig. 13 shows clearly that these elements should be kept at a minimum for best expansion properties.

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†Part I appeared in the June 1932 issue of Metals & Alloys on pages 131-135, 150.

In the case of the nickel-cobalt-iron alloys, equations 4 and 5 show that each % manganese raises by 0.38×10^{-6} per °C. (0.21×10^{-6} per °F.) the lowest expan-

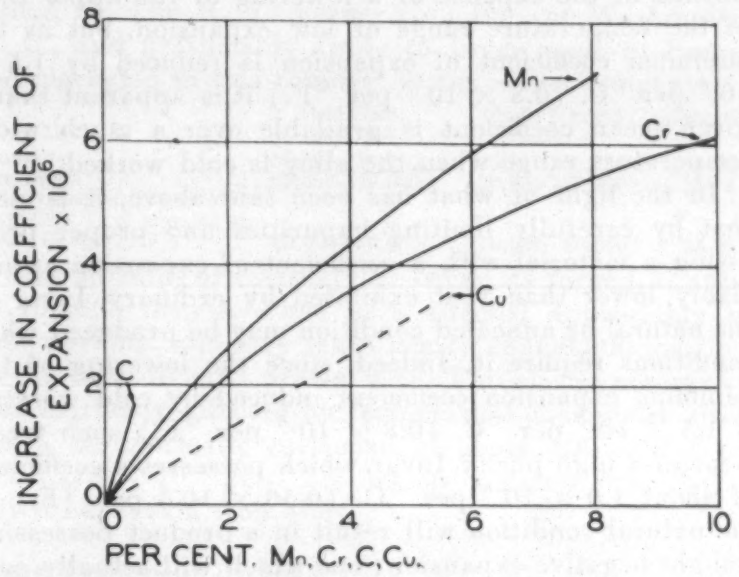


Fig. 13. Increase in the minimum expansibility of the nickel steels when a third constituent is added (Guillaume)

sion coefficient attainable for a given inflection temperature. Contrary to the straight nickel irons, these alloys are benefited by carbon due to the indirect effect of this element in increasing the amount of cobalt which may be present without rendering the alloys unstable. In any case, however, the carbon content must not exceed 0.30% if danger of graphite precipitation is to be avoided.

Effect of Heat Treatment and Cold Work Upon the Expansivity of Invar

In addition to the variations due to the presence of impurities, the expansion characteristics of the alloy of lowest expansivity, Invar, are appreciably modified by heat treatment. Slow cooling increases the expansion while rapid cooling (quenching) reduces it. Cold working is most effective, however, in lowering the expansion as may be shown by the following results secured at the Bureau of Standards.[8]

Linear Coefficient of Expansion × 10^{-6} per °C. at 20°C.			
Treatment	As rolled or cold drawn	Annealed	Quenched
Hot rolled	1.2	1.7	0.7
Cold drawn	0.3	1.2	0.7
Coefficient of Expansion × 10^{-6} per °F. at 68°F.			
Hot rolled	0.7	0.9	0.4
Cold drawn	0.2	0.7	0.4

The expansion coefficient of previously cold worked Invar will increase with subsequent annealing as a function of the temperature up to about 600°C. (1112° F.) at which temperature it reaches its maximum value. This is illustrated by some results of Scott as given in the following tabulation:

Effect of Annealing after Cold Working Alloy Containing 37.2% Nickel and 0.73% Manganese

Annealing temp. °C.	Inflection temp. °C.	Minimum coefficient of expansion per °C.	Temp. range of low coefficient of expansion Min. °C.	Max. °C.
25	235	0.7 × 10–6	0	100
400	240	1.4	0	110
600	255	2.3	0	120
800	250	2.1	0	140

Annealing temp. °F.	Inflection temp. °F.	Minimum coefficient of expansion per °F.	Temp. range of low coefficient of expansion Minimum °F.	Maximum °F.
77	455	0.4 × 10–6	32	212
752	464	0.8	32	230
1112	491	1.3	32	248
1472	482	1.2	32	284

This table also shows that the improvement in the coefficient of expansion induced by cold working is accomplished at the expense of a lowering of the upper limit of the temperature range of low expansion, but as the minimum coefficient of expansion is reduced by 1.5×10^{-6} per °C. (0.8×10^{-6} per °F.) it is apparent that a given mean coefficient is available over a much wider temperature range when the alloy is cold worked.

In the light of what has been said above, it is clear that by carefully limiting impurities and proper processing a material with a coefficient of expansion appreciably lower than that exhibited by ordinary Invar in the natural or annealed condition may be produced when conditions require it. Indeed, since the lowering of the minimum expansion coefficient induced by cold working is 1.5×10^{-6} per °C. (0.8×10^{-6} per °F.) such treatment of a high purity Invar which possesses a coefficient of about 1.0×10^{-6} per °C. (0.56×10^{-6} per °F.) in the natural condition will result in a product possessing a slight negative expansion; one which will actually contract on heating. By subsequent annealing at a carefully selected temperature the expansion coefficient may be brought up to zero so that a product will result in which the expansion will be imperceptible over a considerable temperature range. For most engineering applications, however, such refinement is unnecessary besides being unduly expensive.

Constancy of the Dimensions of Invar

The alloys containing less than 40% nickel are subject to a very slight dimensional instability which is of no moment for the majority of applications but of which it may be necessary to take account in very precise work. When Invar, for example, is heated or cooled to a certain temperature from any other temperature it does not at once assume a constant length but is subject to some transitory length variations. The magnitude and direction of these variations depend upon the two temperatures involved and the rapidity with which the final temperature has been attained. If the bar has been cooled it will slowly elongate in the course of time and, conversely, if it has been heated it will contract. The duration of such changes is always greater if the bar has been cooled than if it has been heated, but in either case the higher the final temperature the greater the speed with which the changes occur. The order of magnitude of these transitory changes is illustrated by some results reported by Guillaume, wherein he showed that a meter of Invar brought to 100°C. immediately after forging elongates at the rate of about 0.067 μ per minute ($\mu = 0.001$ millimeter), whereas, if brought to the same temperature after a long rest at room temperature, it contracts at the rate of 0.8 to 0.9 μ per minute. The contraction is complete in about ½ hour, but if it is heated only to 40° C. it continues for several days.

In addition to these transitory variations, Invar is subject to permanent length changes at constant temperature. Thus a bar of Invar left to itself at constant temperature will gradually elongate following an exponential function of the time as it approaches asymptotically a definite length. The extent of this length increase may be minimized by use of an aging process consisting of subjecting the forged bars to a series of very slowly decreasing temperatures beginning, for example, at 100°C. and ending at 20°C. after several months. Tables and formulae for calculating the extent of these transitory and permanent changes may be found in Bureau of Standards' Circular No. 58.

Composition and Constitution of Invar

Invar is a solid solution of nickel in γ — (austenitic) iron, as are all the low expansion nickel steels. The commercial product will contain about 36% nickel, 0.20%, or less, carbon and approximately 0.70% manganese together with small amounts of the usual impurities of steel.

Magnetic Properties of Invar

Invar is magnetic at ordinary temperatures but loses this property on passing the inflection temperature and becomes paramagnetic at all higher temperatures. This is true of all the high nickel steels.

The alloy is subject to magnetostriction effects; that is to say, longitudinal magnetization produces an increase in length, and, conversely, mechanical elongation increases the magnetization.

Corrosion Properties of Invar

Polished Invar is highly resistant to atmospheric corrosion as well as to attack by fresh or salt water. Invar instruments may be left for long periods of time in moist atmospheres, under water, or even in steam without noticeable effect. But while the corrosion resistance is excellent, it is not perfect, and it is wise to keep Invar apparatus greased when not in use, especially in tropical climes. It is important to prevent inception of attack, for once started extensive damage may be done. A spot of ink will leave a tarnish which will increase if the material is subsequently moistened. Invar is corroded by hydrochloric acid, so that an improperly washed soldered joint may be the starting point of dangerous corrosion. Rough surfaces are distinctly less resistant than polished surfaces.

Physical Properties of Invar

Invar may be forged, rolled, turned, filed, and drawn into wires, although it is so tough that it wears tool edges rapidly. It is readily forgeable, but should be worked slowly. It is very strong and ductile. After the surface layers, which are always more or less cracked on rough bars of high nickel steels, are removed, the metal easily takes a high polish upon which extremely fine lines may be readily ruled.

Some of the physical properties of Invar in the natural (hot rolled or forged) condition are given in the following table:

Melting point	1425°C. (2600°F.) (melts sharply)
Density	8.0 g./cc. (500 lbs./ft.^{3})
Tensile strength	65,000-85,000 lbs./in.^{2}
Yield point	40,000-60,000 lbs./in.^{2}
Elastic limit	20,000-30,000 lbs./in.^{2}
Elongation	30-45%
Reduction in area	55-70%
Scleroscope hardness	19
Brinell hardness	160
Modulus of elasticity in tension	21,400,000 lbs./in.^{2}
Thermoelastic coefficient	500 × 10–6 per °C. (278 × 10–6 per °F.)
Electrical resistance	75-85 microhm-cm. (450-510 Ohms/mil ft.)
Thermal coefficient of electrical resistance	1.2 × 10–3 per °C. (0.67 × 10–3 per °F.)
Specific heat between 25-100°C. (77-212°F.)	0.123 cal./g./°C. (0.123 B.T.U. /lb./°F.)
Thermal conductivity 20-100°C. (68-212°F.)	.025 cal./sec./cm.^{2}/cm. thickness/°C. temp. difference (72.6 B.T.U./hour/ ft.^{2}/in. thickness/°F. temp. difference).

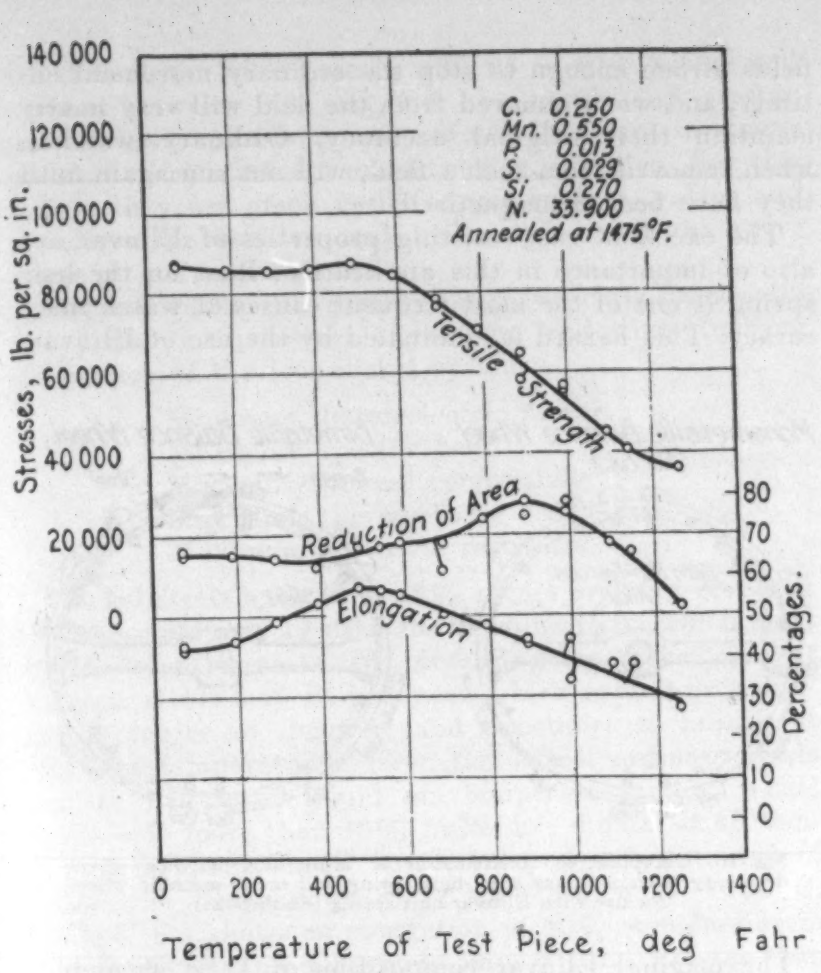


Fig. 14. Tensile properties at high temperatures of a forged 34% nickel steel (MacPherran)

Mechanical Properties of Invar

A tensile strength about midway between the limits shown in the table may be expected from a properly made low carbon Invar. The elastic limit is the only property which is greatly affected by heat treatment as may be shown from the following tests reported in B. of S. Circular No. 58 for a steel containing 0.08% carbon, 0.5% manganese, and 36% nickel:

Treatment	Tensile Strength lbs./in.²	Elastic Limit lbs./in.²	Elong. %	R.A. %
As rolled	76,500	36,500	36.3	65.6
Annealed from above 790°C. (1454°F.)	72,500	24,000	39.2	67.5
Quenched from above 760°C. (1400°F.)	70,500	20,000	38.0	58.3

These results indicate that the strength and elastic properties of Invar are lowered by the stabilizing heat treatments. No notched bar impact test results are available, but it is known that Invar is very tough so that it may be used for machine parts which are subject to violent shocks.

While carbon exerts less effect on the mechanical properties of Invar than it does on ordinary steels, its influence is far from negligible as is evidenced by the following results taken from a paper by Giesen.[9] The steels involved contained less than 0.15% each of manganese and silicon.

Carbon %	Tensile Strength lbs./in.²	Yield Point lbs./in.²	Elong. %	R.A. %
0.15	71,000	60,000	35.5	71.8
0.30	115,000	68,000	38.3	78.6
0.95	112,000	87,000	39.1	62.7

Owing to the adverse effect of carbon on the expansion coefficient, Invar would not ordinarily be made with more than about 0.15% of this element, but if higher strengths should be necessary for special applications, increased carbon may be resorted to if the resulting higher expansivity is acceptable.

The tensile properties of Invar at elevated temperatures are good but not exceptional. MacPherran[10] has determined the variation in these properties with temperature for a forged 34% nickel steel annealed at 802°C. (1475°F.). His results are reproduced in Fig. 14. A few results obtained by Hatfield[11] upon a steel of Invar composition are given in the following table:

C %	Mn %	Si %	Ni %	Temp. of Test °C.	Temp. of Test °F.	Yield Point lbs./in.²	Max. Stress lbs./in.²	Elongation %	Reduction of Area %
0.23	0.35	0.12	36.5	15	59	48800	90500	44.5	64.0
				800	1472	.....	17600	37.5	33.7

Since Invar is useful chiefly because of its low expansivity, it is not likely to be used out of the temperature range where this property is available; which is to say, that its use is more or less limited to temperatures below the inflection temperature.

Cold working strengthens the material with accompanying loss in ductility. The following data were furnished by The R. Y. Ferner Co., Inc., of Washington, D. C., and presumably apply to Invar made in France and marketed in this country by the above company:

Condition	Yield Point lbs./in.²	Tensile Strength lbs./in.²	Elongation %
Natural	55,000- 80,000	80,000-100,000	30-20
Wire Drawn	85,000-110,000	90,000-120,000	15- 8
Water quenched from 950°C. (1742°F.), or annealed at 950°C. (1742°F.)	40,000- 45,000	70,000- 80,000	35-25

The modulus of elasticity of Invar, as forged, is about 21,400,000 lbs./in.², but it is affected appreciably by cold working, and may reach nearly 23,000,000 lbs./in.², in the case of hard drawn wire. The elastic modulus is also markedly affected by temperature changes as Invar has a thermoelastic coefficient of about 500×10^{-6} per °C. (278×10^{-6} per °F.), which is higher than that of any other nickel iron alloy.

Heat Treatment of Invar

Being austenitic at all temperatures (see later section "Constitution of the Iron-Nickel Alloys"), Invar is not amenable to heat treatment in the ordinary sense. Annealing to relieve strains may be carried out at 760° to 820°C. (1400°-1500°F.) but, as indicated above, the alloy should be quenched rather than slowly cooled if best expansion properties are to be obtained. Annealing subsequent to cold working will nullify the improvement in the expansion characteristics induced by the cold working.

Physical Properties of the Alloys of Specific Expansion Properties

For purposes of reference, tables and charts of the variations in some of the more important physical properties with nickel content throughout the range considered in this article (25 to 60%) are given in section "Variation in Some Physical Properties with Nickel Content of Iron-Nickel Alloys Containing from 20 to 60% Nickel."

ALLOYS OF LOW THERMAL COEFFICIENT OF ELASTICITY

It was stated in the previous section that Invar possesses the highest thermal coefficient of elasticity of any of the iron-nickels. This fact is illustrated in Fig. 15, which shows the variation of the temperature coefficient with nickel content according to Guillaume. This curve also indicates that at compositions of 29 and 45% nickel two alloys exist which possess zero thermoelastic coefficients at 20°C. (68°F.). Advantage cannot readily be taken of this fact for the commercial production of steels with an invariable elastic modulus because both compositions are so very sensitive to nickel content that the smallest error in composition, or even lack of chemical homogeneity in the same casting would result in ap-

preciable variations in the modulus. In the case of watch springs it has been found that the error due to this cause in a watch movement may attain a value of the order of 25 seconds per 24 hours in the temperature interval between 0° and 30°C. (32° and 86°F.).

The addition of 12% chromium, or its equivalent where small quantities of manganese, tungsten or carbon are also included, results in a lowering of the thermo-elastic coefficient curve to the position shown in Curve B,

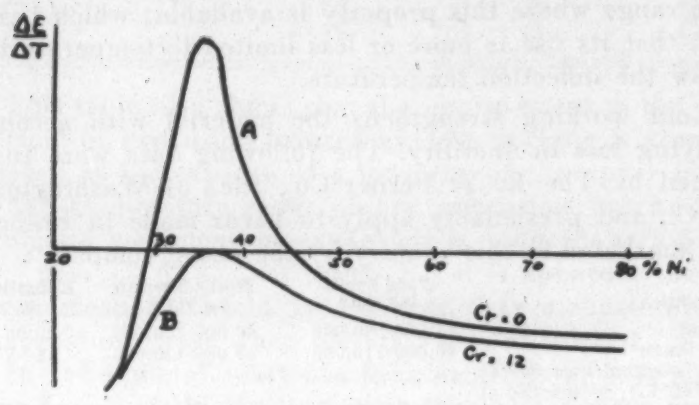


Fig. 15. Variations in the temperature coefficient of modulus of elasticity of nickel steels with nickel content at 20°C. (68°F.) (Guillaume)

of Fig. 15. The maximum remains at about 36% nickel, but is lowered to such an extent that it is tangent to the zero axis, and at the same time is flattened so that it is much less sensitive to variations in nickel content than either of the zero points on Curve "A." Steel of this composition, which is in effect an Invar in which 12% of the iron has been replaced by chromium, has been given the designation "Elinvar" because of its invariable elasticity. As in the case of Invar, the credit for the discovery and development of this alloy is due to Guillaume.

Elinvar has been found to be particularly valuable as a material for the construction of hair springs for watches and other precision instruments. In watches employing the ordinary steel hair spring it is necessary to compensate for the variations in the elasticity of the spring induced by temperature fluctuations by use of a complicated bimetallic balance wheel constructed of brass and steel and cut at two places on the circumference as shown in Fig. 16. Substitution of an Elinvar hair spring permits the use of a simplified, uncut, mono-metallic, non-magnetic balance wheel. The new type of construction results in accurate compensation over a wide temperature range instead of at two definite temperatures only as is the case with the older method of compensation. Timepieces equipped with Elinvar hair springs and non-magnetic balance wheels also have the important added advantage of not being permanently affected by magnetic influences of considerable strength. The behavior of the two types of assembly in a magnetic field is illustrated in Fig. 17.[12] Watches equipped with the improved movement will continue to run in fields strong enough to stop the ordinary movement entirely, and when removed from the field will very nearly maintain their original accuracy. Ordinary watches, when removed from such a field, will not run again until they have been demagnetized.

The excellent rust-resisting properties of Elinvar are also of importance in this application. Rust on the hair spring is one of the most frequent causes of watch inaccuracy. This hazard is eliminated by the use of Elinvar.

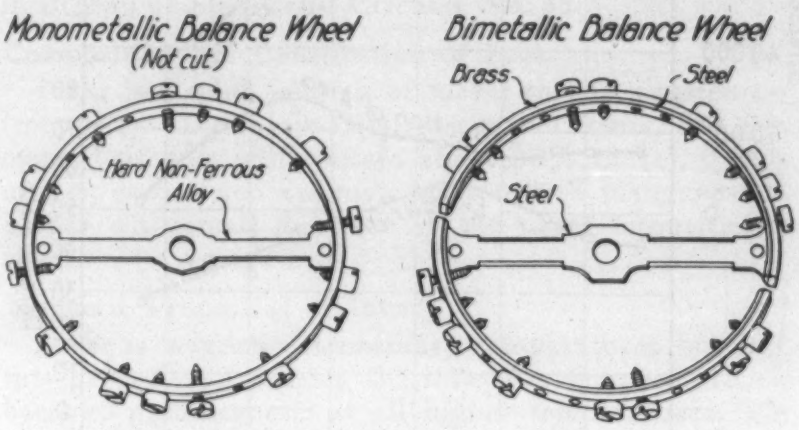


Fig. 16. Comparative construction of bi-metallic balance wheel necessary with ordinary steel hair spring and mono-metallic wheel for use with Elinvar hair spring (Shubrooks)

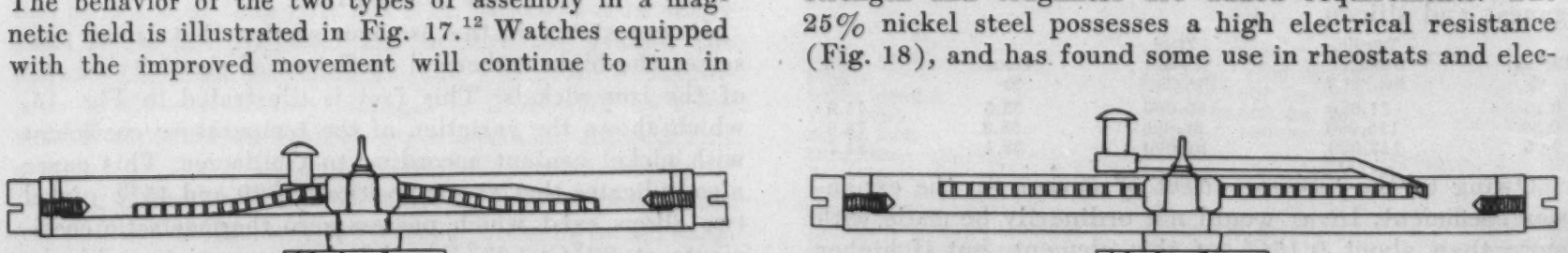
The original Elinvar composition of 12% chromium and 36% nickel has been considerably modified during the years since its discovery. At the present time the compositions of most of the Elinvars used for hair spring purposes are stated by Shubrooks[13] to fall within the following range:

Nickel	33—35%
Iron	61—53%
Chromium	4— 5%
Tungsten	1— 3%
Manganese	0.5— 2%
Silicon	0.5— 2%
Carbon	0.5— 2%

Another application of this interesting alloy is in the manufacture of tuning forks for precision work.[14] Elinvar tuning forks will maintain their constancy of frequency at any atmospheric temperature likely to be encountered in any climate. For this reason such forks have been used as frequency standards in radio engineering, whereby the fork is used to maintain an oscillating circuit at a predetermined frequency.[15]

MISCELLANEOUS IRON-NICKEL ALLOYS

Nickel steels containing 20 to 30% nickel remain austenitic on cooling at relatively slow rates, and in this condition are non-magnetic. For this reason they are valuable for non-magnetic parts, especially when high strength and toughness are added requirements. The 25% nickel steel possesses a high electrical resistance (Fig. 18), and has found some use in rheostats and elec-



A—Cross section of watch balance with ordinary steel hairspring and bimetallic balance wheel, showing effect of magnetization

B—Cross section of balance with Elinvar hairspring and mono-metallic balance wheel

Fig. 17. (Thas [12])

trical heaters. Nickel steels with 25 to 40% nickel and carbon between 0.3 and 0.5 are tough and strong, possess low expansivity and are very resistant to atmospheric and either fresh or salt water corrosion. For this reason they are much used for gas engines, valves and spindles, for ignition and boiler tubes and for valve stems on sea water pumps.

The low carbon 35% nickel steel, which is practically the Invar composition, shows the following limiting properties of the iron-nickel system:

Minimum thermoelectric power.
Maximum specific heat.
Minimum thermal conductivity.
Maximum thermoelastic coefficient.
Maximum electrical resistance.

Nickel steels with 35 to 38% nickel are very resistant to shock, and may be used for machine parts which must resist violent impacts. By increasing the nickel content further, steels may be produced which exhibit an astonishing degree of ductility and resistance to impact at very low temperatures. Even the softest ordinary steels become brittle at liquid air temperatures, but nickel steels with more than 40% nickel are ductile at all temperatures. Chevenard[16] has developed and patented in France an alloy known as "AMF," which at —190°C. (—310°F.) shows an elongation of 40%, a reduction in area of 55%, and a Fremont impact value greater than 45 kg./cm.^{2} combined with a tensile strength of 114,000 lbs./in.^{2} This alloy appears to contain 55 to 60% nickel, together with 1 to 3% manganese, and 0.2 to 0.4% carbon. The alloy is valuable for parts of machinery used in commercial liquid air plants such as valves for expansion engines, which parts are subjected to violent shocks at very low temperatures.

CONSTITUTION OF THE IRON-NICKEL ALLOYS

Some light may be thrown upon the various phenomena exhibited by the iron-nickel alloys discussed in the previous sections by a consideration of the equilibrium diagram for this system. The representation shown in Fig. 19[17] based primarily on the work of Hanson and Hanson, Hanson and Freeman, and Honda and Miura is the most up-to-date and probably the most accurate available at the present time although there are

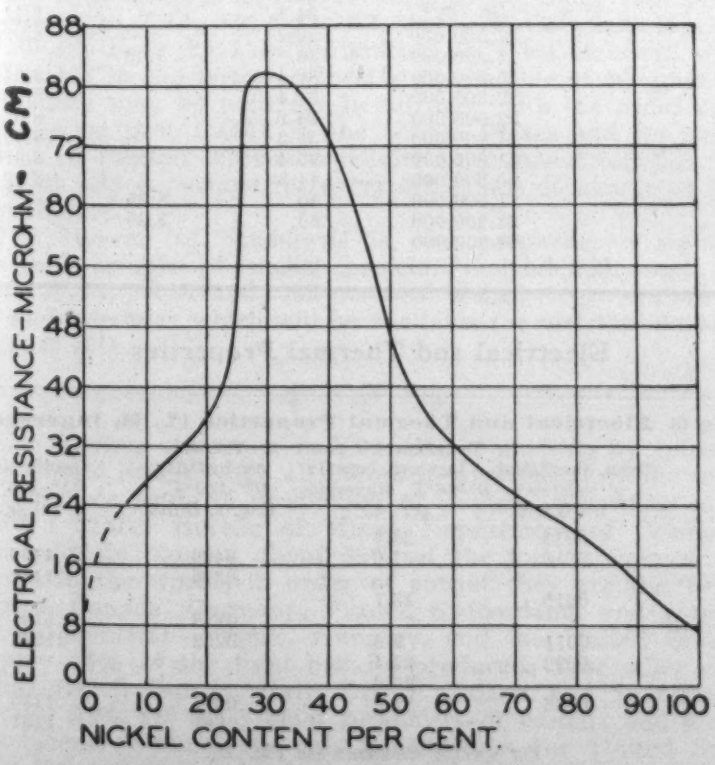


Fig. 18. Variation of electrical resistance with nickel content

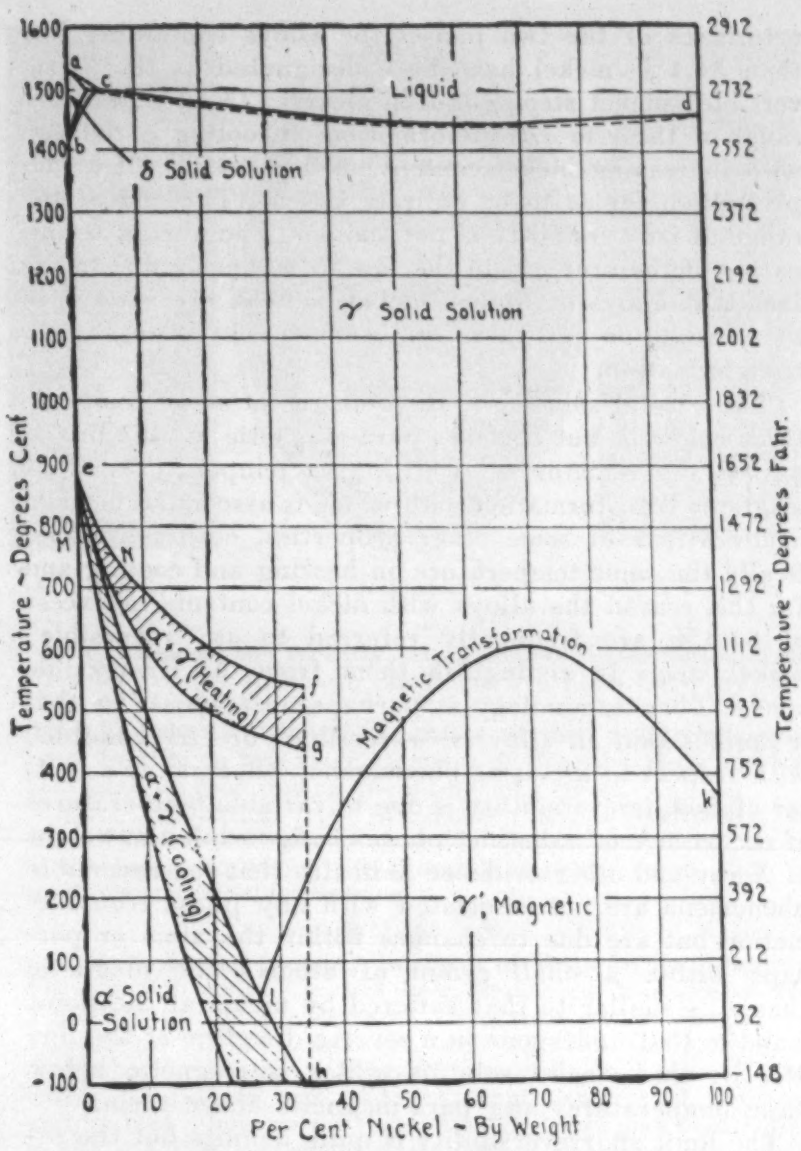


Fig. 19. Iron nickel equilibrium diagram (Merica)

many questions about this system which even now are not clearly understood, if at all.

According to our present conception, iron and nickel mix in all proportions in the solid state to form an uninterrupted series of solid solutions, which, however, may under certain conditions exist in three separate phases, designated as α, γ and δ solid solutions. The δ solid solution is unimportant as its existence is confined to the restricted area *abc*. Its characteristics are precisely those of the α phase.

The γ solid solution, which is characterized by a face-centered cubic lattice, exists alone throughout the entire region below *bcd* with the exception of the area under *efh* regardless of the thermal history of the alloys. However, when the alloys containing less than 34.4% nickel are slowly cooled a change from the face-centered γ phase to the body-centered α phase takes place in the region *eih*, below which the alloys will consist wholly of the α phase. If they are then slowly reheated the reverse transition from the α to the γ phase will be delayed until the region *egf* is attained. Due to this extreme hysteresis the true equilibrium temperatures of the transformation cannot be determined. The best that can be done is to indicate on the diagram the temperature ranges actually observed on slow heating and cooling. Present opinion inclines toward the belief that there is somewhere between these two ranges a region of heterogenous equilibrium within which both the α and γ phases may exist together in stable form.

Because of the wide separation of the temperatures of occurrence on heating and cooling of the marked modification of physical properties due to the different char-

acteristics of the two phases the alloys containing less than 34.4% nickel have been designated as the "irreversible" nickel steels, or iron-nickels. The temperature range of the γ to α transformation on cooling is reduced with increasing nickel content until at 34.4% it is depressed so far as to be entirely absent. The end of the range of irreversibility is not sudden. The abrupt termination of the area *efg* in the line *fg* is simply due to the fact that alloys of higher nickel content are always in the γ condition and therefore cannot undergo any α to γ transformation.

The γ solid solution is ferro-magnetic at all temperatures below *lk* but becomes para-magnetic as this line is passed and remains so at all higher temperatures. This magnetic transformation with which is associated marked modifications of some other properties, occurs at practically the same temperature on heating and cooling and for this reason the alloys with nickel contents in excess of 34.4% are frequently referred to as "reversible" nickel steels to distinguish them from the irreversible steels. This terminology is perhaps unfortunate in that it implies that an alloy is "reversible" or "irreversible" with respect to the same phenomena, whereas, as a matter of fact, irreversibility is due to variable temperatures of occurrence of a distinct phase change while the weight of X-ray and other evidence indicates that the reversible phenomena are not associated with any phase transformation but are due to changes within the atom or perhaps within a small group of atoms. The magnetic change is similar to that suffered by nickel at the point *k* and to that undergone in a reverse direction at the line *MN* by the α solid solution which is magnetic below these temperatures and para-magnetic above them.

The limit of irreversibility is quite definite but the reversible effects may persist into the irreversible field insofar as the γ constituent is present. Alloys containing from 26 to 34% nickel may show either or both transformations depending on their previous thermal treatment.

One of the most pronounced effects associated with the magnetic transformation is the variation in the dilation properties of the alloys containing nickel between 30 and 78%. In these alloys this temperature of magnetic change marks the upper limit of the temperature range of low expansivity and is therefore identical with the "inflection temperature" discussed in the first section ("Alloys with Low or Specific Expansion Properties").

It is evident from what has been said that the irreversible alloys are amenable to heat treatment in much the same manner as ordinary steel. The separation of the α from the γ constituent takes place on cooling in a manner similar to that obtaining during the formation of martensite in steel. Even after comparatively slow cooling the alloys containing in excess of 10% nickel are hard and similar to martensite in structure and are for this reason frequently referred to as martensitic nickel steels. With rapid cooling, the transformation range *eih* is still further depressed so that the martensitic steels may be kept in the γ condition at ordinary temperatures by suitable quenching. In this condition they will be non-magnetic if their composition lies to the left of *lk*. It is thus possible to maintain the same steel at room temperature in either the hard, magnetic martensitic condition or in the relatively soft non-magnetic γ state. In contradistinction to ordinary steel, these martensitic alloys must be quenched in order to be softened and slowly cooled when hardness and strength is the objective. In this respect they are similar to the well-known chromium-nickel corrosion resistant steels of the 18-8 type.

The alloys beyond the range of irreversibility, being always in the γ state, are only moderately hard under all conditions and can be strengthened only by working.

VARIATION IN SOME PHYSICAL PROPERTIES WITH NICKEL CONTENT OF IRON-NICKEL ALLOYS CONTAINING FROM 20 TO 60% NICKEL

Table 3. Tensile Properties[8]

Nickel %	Manganese %	Carbon %	Treatment	Tensile Strength lbs./in.²	Elastic Limit lbs./in.²	Elongation %	Reduction of area %
26.0	1.50	0.20	As rolled	78500	12000	50.0	70.7
			Quenched	76000	15000	49.5	70.5
30.0	1.50	.15	As rolled	90000	27000	39.5	69.7
			Annealed	84500	28000	46.5	68.5
			Quenched	81500	23000	44.2	70.5
30.0	2.00	.40	As rolled	105000	45000	47.0	66.6
			Annealed	101500	35000	46.5	66.4
			Quenched	91000	25000	45.7	69.3
32.3	2.30	.12	As rolled	82000	30000	37.5	65.6
			Annealed	77500	22000	43.0	66.2
			Quenched	73000	18600	39.5	64.7
35.1	1.50	.22	As rolled	89000	30000	40.6	67.5
			Annealed	85000	30000	42.0	67.3
			Quenched	82000	27500	41.0	65.0
36.0	.50	.08	As rolled	76500	36500	36.3	65.6
			Annealed	72500	24000	39.2	67.5
			Quenched	70500	20000	38.0	58.3
43.0	1.50	.35	Cold drawn	100000	52500	16.2	46.0
45.0	1.50	.37	As rolled	107000	40000	40.0	51.1
			Annealed	94500	35000	43.7	51.1
			Quenched	73000	19500	38.0	46.3
50.7	1.25	.17	As rolled	99000	48500	38.5	67.7

Steels from The Midvale Co.
Annealed from above 790°C. (1450°F.)
Quenched from above 760°C. (1400°F.)

Table 4. Elastic Modulus (Guillaume)

Nickel %	Modulus of Elasticity lbs./in.²
24.1	27,500,000
26.2	26,400,000
27.9	25,800,000
30.4	22,800,000
31.4	22,000,000
34.6	21,900,000
35.2	21,200,000
37.2	20,800,000
39.4	21,500,000
44.3	23,200,000
70.0	28,200,000

Table 5. Density

% Nickel	Density in g./cc Hegg	Guillaume
20.	8.02	
24.1		8.111
26.2		8.096
30.	8.06	
30.4		8.049
31.4		8.008
34.6		8.066
37.2		8.005
39.4		8.076
44.3		8.120
50.	8.05	
60.	8.29	

Electrical and Thermal Properties

Table 6. Electrical and Thermal Properties (L. H. Ingersoll)

Nickel %	Temp. Coefficient of resistance 0°-100°C.	Thermoelectric power (against copper). 0°-96°C. Microvolts per °C.	Thermal conductivity 20°-100°C. C. g. s. Units	Specific Heat 25°-100°C. cal./g.
21.0	.0018	23.5		
22.1	.0018	21.0	.0490	.1163
25.2			.0320	.1181
26.4	.0016	16.7		
28.4			.0278	.1191
35.1	.0011	9.8	.0262	.1228
40.0	.0022	22.4		
45.0		29.0		
47.1	.0036	31.9	.0367	.1196
75.1			.0691	.1181

For specific resistance see Fig. 18.

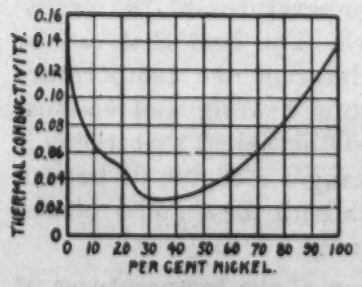


Fig. 20. Variation of thermal conductivity in C.g.s. units with nickel content (Ingersoll)

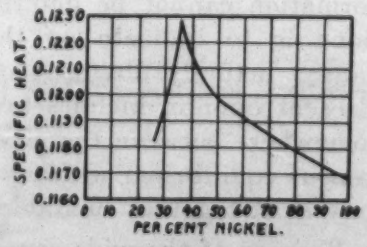


Fig. 21. Variation of specific heat in cal./g./°C. with nickel content (Ingersoll)

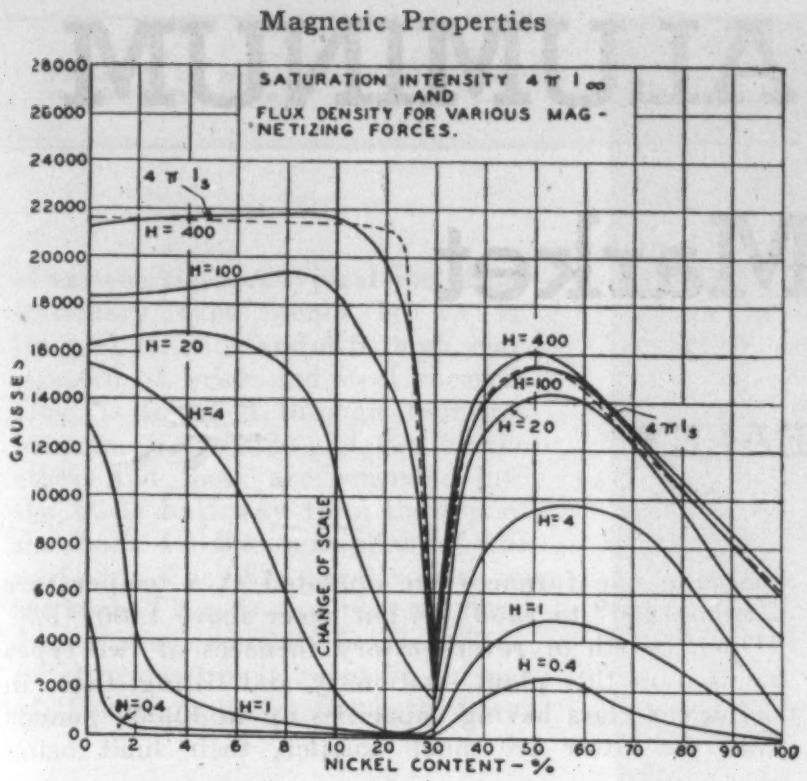


Fig. 22. Magnetic properties of iron-nickel alloys (Yensen)

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The U. S. Bureau of Standards has added a standard sample of nitralloy G steel (Cr, Mo, Al) and of silica brick to its list of standard samples. The steel has the following composition: Carbon 0.342, Manganese .481, Phosphorus .021, Sulphur .019, Silicon .250, Chromium 1.29, Molybdenum .163, Aluminum 1.06, Copper .141 and Nickel .131. This standard which is No. 106 in the series costs $3.00 per sample of 150 grams. The composition of the silica brick is as follows: SiO_2 93.94, Al_2O_3 1.96, Fe_2O_3 .66, TiO_2 .16, ZrO_2 .02, P_2O_5 .02, MnO .005, CaO 2.29, MgO .21, Na_2O .06, K_2O .29, Loss on ignition .38. This standard which is No. 102 in the series costs $2.00 per sample of 60 grams.

Samples may be paid for in advance with the order or be sent parcel post C.O.D. in the United States and its possessions. All foreign shipments require prepayment together with 30 cents added postage for every 300 grams of sample or fraction thereof.

The Bureau of Standards is also preparing a standard analyzed sample of nickel-chromium-molybdenum cast iron No. 103 (approximately .88 per cent nickel, .16 chromium and .70 molybdenum) which will be available for distribution about August 15th.

◈ ◈ ◈

Considering aluminum and bauxite production by countries the United States leads all others in production of the metal, and France leads in production of bauxite, according to the United States Bureau of Mines, Department of Commerce. Six countries supply about 88% of the total aluminum produced in the world; in order of output they are the United States, Canada, Germany, France, Switzerland, and Norway. Three countries—France, Hungary, and the United States—supply 66% of the total bauxite produced; four other countries—Dutch Guiana, Italy, British Guiana, and Jugoslavia—supply 32%. Of the 7 chief producers of bauxite and 6 chief producers of aluminum only 2 countries—the United States and France—appear in both groups.

J. T. Nichols J. C. Whetzel E. S. Taylerson

J. C. Whetzel has recently been appointed Assistant to Vice President of the American Sheet and Tin Plate Company. Mr. Whetzel entered the employ of the Sheet and Tin Plate Company in 1920 as Research Associate at their research laboratory. In 1922 he was made Manager of this laboratory and has held that position during the intervening years.

After graduating from Washington & Lee University, he studied Chemical Engineering at the Massachusetts Institute of Technology, and during the World War served as an officer in the Chemical Warfare Service.

◈ ◈ ◈

E. S. Taylerson, formerly Engineer of Tests for the American Sheet & Tin Plate Co., has been appointed Manager of the Tin Plate Company's Research Laboratory at 210 Semple St., Pittsburgh. Mr. Taylerson has been with this Company since 1917 when he became a Research Associate at the same Laboratory. In 1922 he was made Assistant Director of Research and in 1924 Engineer of Tests. Mr. Taylerson has been active in the A.S.T.M. committee work during recent years and is a member of American Institute of Mining & Metallurgical Engineers, American Iron & Steel Institute, American Chemical Society, American Society for Testing Materials, American Society for Steel Treating, American Electrochemical Society, American Physical Society, Optical Society of America, Engineers Society of Western Pennsylvania, Institute of Metals and the Iron & Steel Institute.

◈ ◈ ◈

J. T. Nichols has been appointed Assistant Manager of the American Sheet & Tin Plate Company's Research Laboratory at 210 Semple Street, Pittsburgh. Mr. Nichols has been with this Laboratory since 1925 as Engineer-Physicist. He was graduated from the Massachusetts Institute of Technology in 1922 and, before coming to Pittsburgh, was engaged in aerodynamic research carried on at that school for the Engineering Division of the U. S. Army Air Service. He is a member of the American Institute of Electrical Engineers and the Engineers Society of Western Pennsylvania.

◈ ◈ ◈

Dr. R. F. Mehl, formerly Assistant Director of Research, American Rolling Mill, is now Director of the Bureau of Metallurgical Research, Carnegie Institute of Technology.

◈ ◈ ◈

Announcement has just been made of the appointment of **Merrill G. Baker** as executive assistant to Albert C. Lehman, president of Blaw-Knox Company, Pittsburgh. The appointment was effective on June 1. For several years Mr. Baker was associated with Ford, Bacon & Davis, Inc., engineers, New York, in the capacity of assistant to the vice-president.

◈ ◈ ◈

At the recent annual meeting of The Electrochemical Society, the following new officers were elected: President, **R. A. Witherspoon;** 3 Vice Presidents, **Duncan MacRae, E. M. Baker,** and **Sterling Temple;** Managers, **Acheson Smith, O. P. Watts,** and **W. S. Landis;** Treasurer, **R. M. Burns,** and Secretary, **Colin G. Fink.**

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Earl H. Seelbach, 381 Ellicott Square, Buffalo, N. Y., will have charge of the engineering and sales of Despatch industrial ovens including Despatch paint straining and finish conditioning equipment and heat treating ovens including material handling systems of all kinds in the western section of New York State.

PREPARING ALUMINUM for the Market

By J. B. NEALEY*

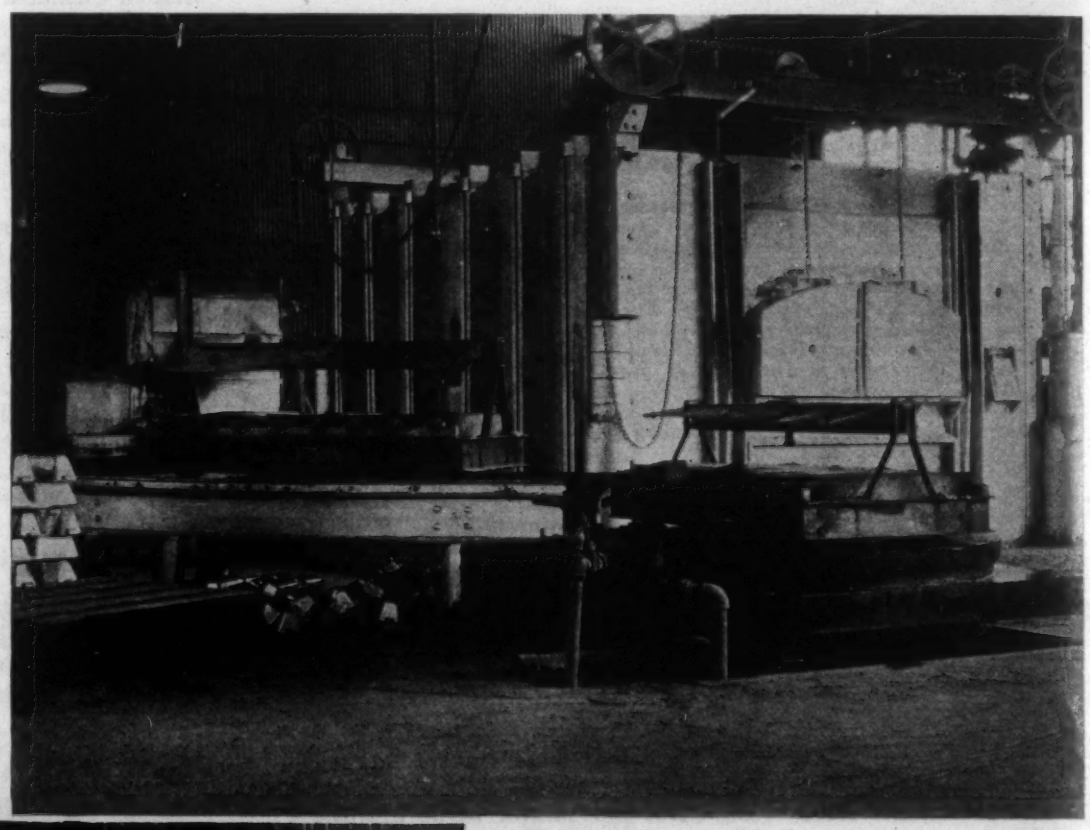
ALUMINUM straight from reduction pots or electrolytic cells is not the aluminum of commerce, it must be further refined to remove non-metallic impurities. It is frequently alloyed with other metals to bring out the various physical characteristics for which it is so justly famed, and it must be cast into various type ingots for specific purposes and for convenience in handling. All of these are accomplished in a single remelting in gas fired furnaces. At least this is the practice at the Cleveland Plant of Aluminum Company of America.

When the pig from the reduction works is refined under carefully controlled conditions, inclusions such as oxides, dross, electrolyte, etc., are eliminated. For this operation and in making aluminum alloys from virgin aluminum, the furnaces are operated at a temperature of from 1250° to 1350° F. but never above 1400° F.

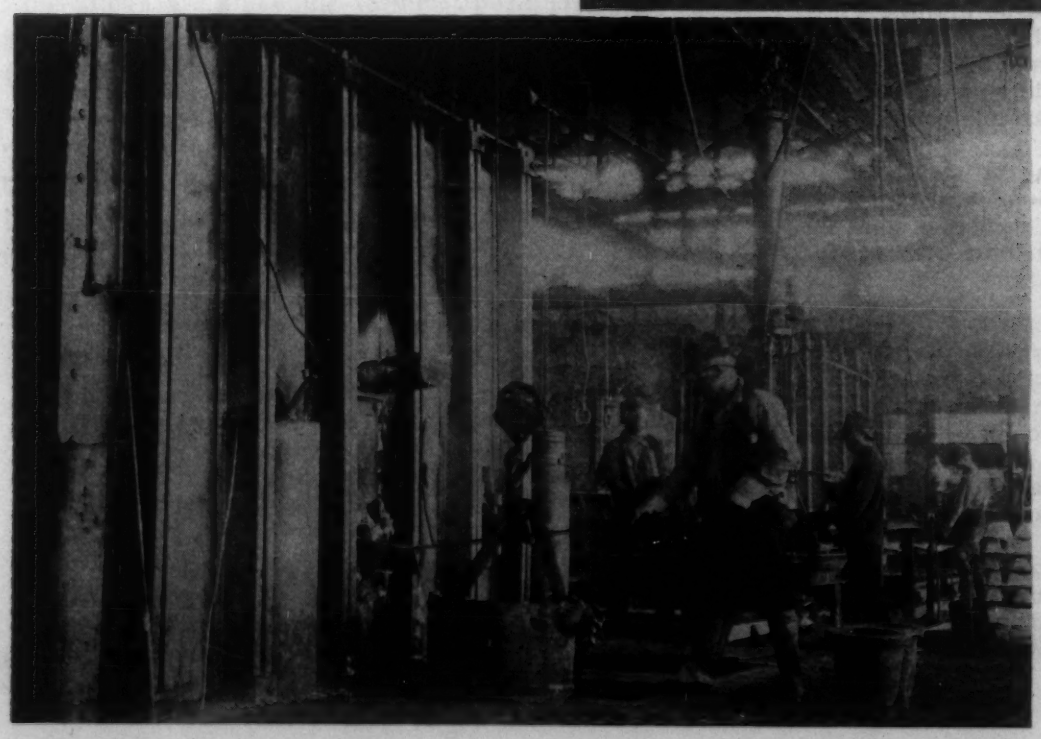
Open hearth or reverberatory furnaces of two types are used in this plant, stationary and tilting, those in the former class having capacities up to 30,000 pounds while the latter are much smaller, their limit being around 3,000 pounds. These furnaces can be either operated continuously or by the batch method. When charging the pigs are laid on the hearth and melt at the rate of 1500-2000 pounds per hour, and when a full charge has been obtained the hardeners are added and thoroughly mixed after which the alloy is tapped and run into the proper shaped molds.

In one immense building there are grouped many reverberatory furnaces

*American Gas Association.

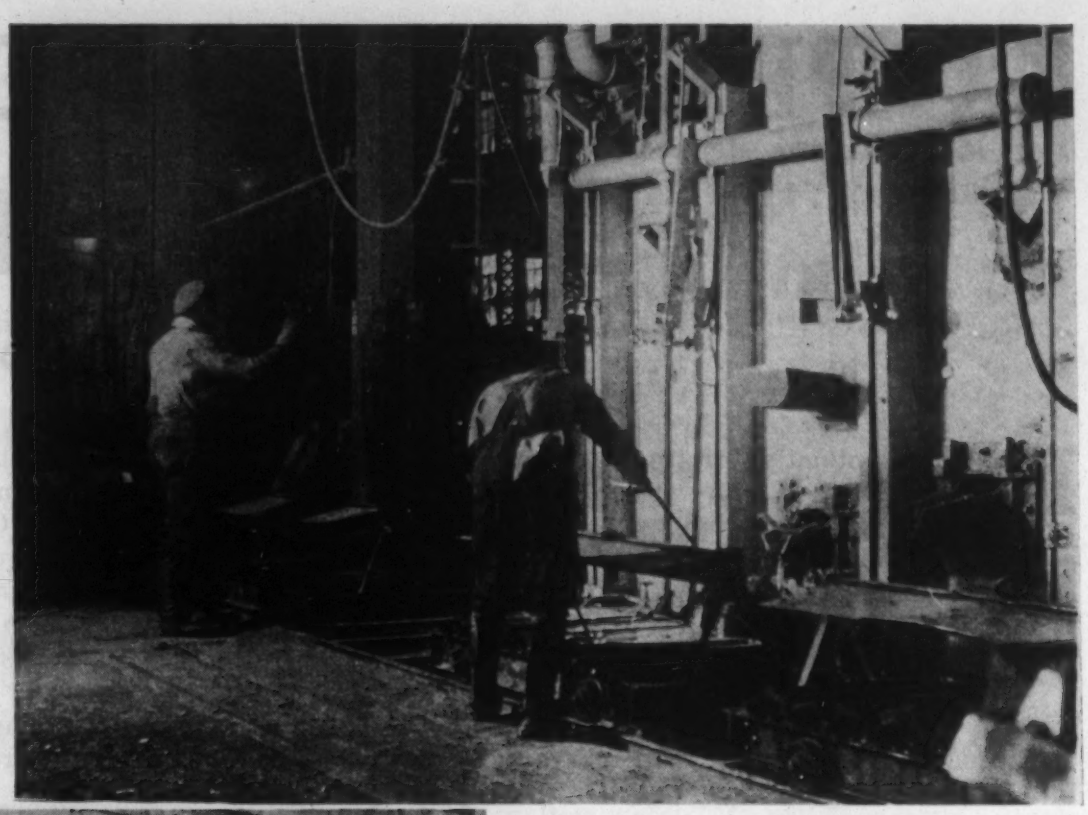


Ingot mold equipment used in pigging 20,000 lb. reverberatory furnaces.



Tapping 30,000 lb. furnace. The metal will be transferred in the 800 lb. ladle to smaller holding furnaces.

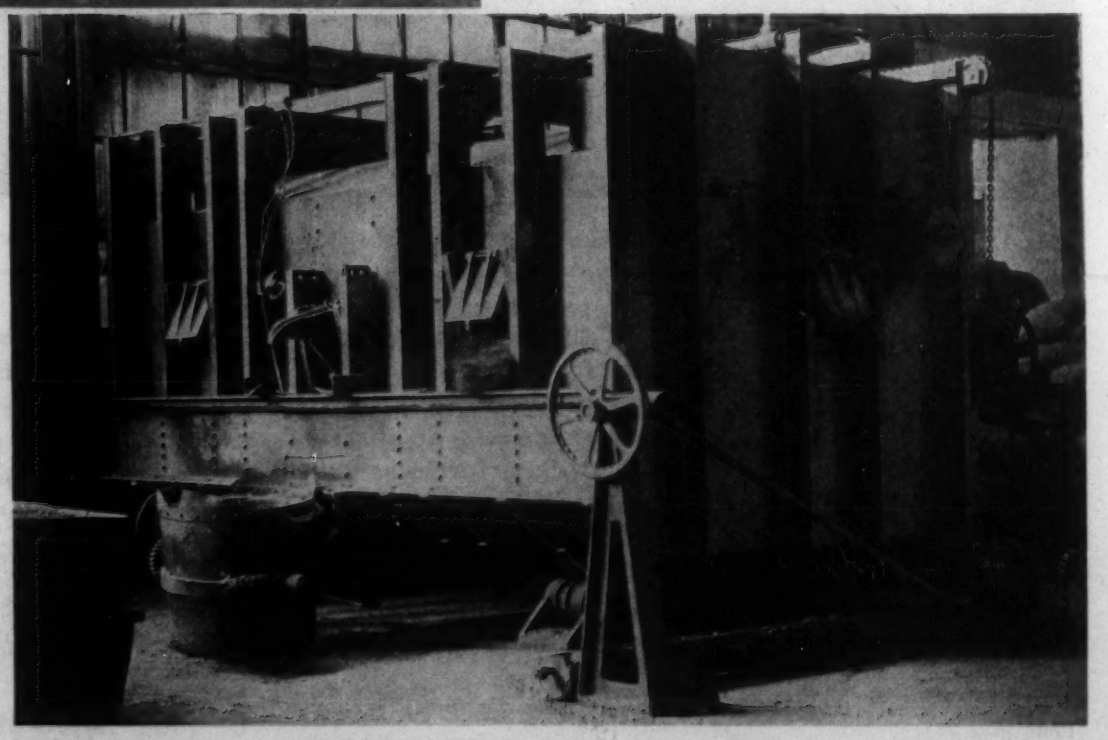
Pigging 30 lb. ingots from 10,000 lb. gas fired reverberatory furnace.



of various sizes. A typical one of the stationary type would be 15 ft. long, 11 ft. wide and 8 ft. high, constructed of brick and steel encased. Heat is supplied through four gas burners on one side and two on the other, and these are cemented into the walls half way from the top of the bath to the springline of the roof arch. They fire directly down on the bath. There is a counter weighted door at each end of the furnace. Temperature control is aided by the use of thermocouples in the bath direct

Knocking out ingots from ingot molds after pigging 20,000 lb. reverberatory furnace in background.

construction but smaller, a typical size being 10 ft. in length and 7 ft. in cross section. It sets on two semicircular castings and these in turn bear on a pair of rollers each for the tilting operation. The arch is supported by buckstays rising above the furnace side walls. At one end is the charging door, and the tap hole and spout are at the other end. Heat is furnished by two gas burners, one in each side, firing down on the bath.



connected to an indicating pyrometer.

The metal when ready for casting in its final form is tapped through a single hole and spout on either side directly into molds. Pits on each side of the furnace and parallel to it, are used in the tapping operation. Down the center of these pits, and at floor level, is a track on which the mold frames with wheels are pushed into position.

The tilting furnaces are similar in

3,000 lb. tilting type furnace.

COPPER TIN COMPOUND IN BABBITT

By GEORGE A. NELSON*

IN THE examination of tin base bearing metals, the author has noted many types of crystal structures, which seemed somewhat vague in regard to the appearance of the CuSn compound which is usually found in these examinations.

The literature on the subject gives the following characteristics of this structure.

"White needles are of the intermetallic compound CuSn."

"Primary needles of CuSn separate from solution in the form of long, feathery or chain-like crystals generally arranged in a very distinct angular fashion.[1]

"When the pouring temperature is lower, the CuSn occurs chiefly as shorter and often much thicker needle-shaped crystals or in star shaped forms.[2]

The appearance of all these mentioned forms is usually found in micro-examinations. Fig. 1 shows the typical appearance at 100 magnification. The determination of the reasons for these various formations was the motive for this investigation.

Fig. 1. Tin Base Babbitt Mag. 100X. Structure of SbSn cubes and CuSn particles imbedded in eutectic background.

Samples of standard grades of tin base babbitt were obtained and cooled very slowly from the molten temperature. Specimens were cut from the centers of the samples and polished with decreasing sizes of abrasive ending with No. 00 Emery Paper. A departure was made from the usual method of etching which did not necessitate further polishing on the wet cloths.

The usual time for etching is about 5 seconds, which discolors the eutectic background and leaves a pattern that can be studied by the metallurgical microscope. In this instance, the eutectic was the portion that was desired to be entirely eliminated in order to study the framework of CuSn and SbSn. Various etches were tried with the final choice of a solution of 25% nitric acid in water. This violently attacked the eutectic but had very little effect on the 2 compounds. The acid solution of FeCl worked satisfactorily but required a much longer time; a matter of 2 days.

After etching, a black residue clung to the crystals. This disappeared after boiling in sodium hydroxide solution.

The specimens were photographed from 2 different angles, obtaining a stereoscopic micrograph. To obtain a clear understanding of the following points, the photographs should be viewed through a stereoscope.*

Following is the analysis of the babbitts obtained:

Sample No.	Sn	Sb	Cu
1	88	10	2
2	88	8.5	3.5
3	88	6.5	5.5
4	83.4	8.3	8.3

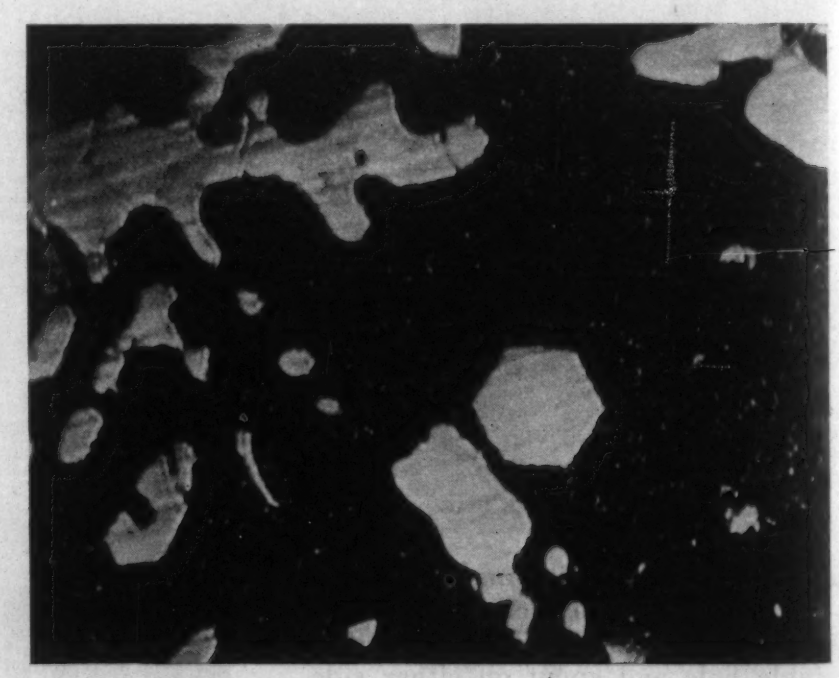


Fig. 2. Cross Section of CuSn needle. Mag. 1000X. Shows perfect hexagonal shape.

Fig. 5* of Sample 1 shows a compact network of single plate copper tin needles extending in many directions. There are no evidences of stars and no traces of ringlets or unattached fragments. The SbSn compound is evident by its cubical formation. These cubes are found imbedded in the eutectic background, clinging to the needles and being penetrated by the needles.

Fig. 6* shows the appearance of Sample 2. It is noted that the network is coarser than that of Sample 1. The plates are in bundles, the bundles running in several

*Shaw Laboratory, San Francisco.

[1]National Metals Handbook. American Society for Steel Treating, 1930, page 781.

[2]Hudson & Darley. *Journal Institute of Metals,* Vol. 24, 1920, page 368.

*For Figs. 5 to 8 please turn to the coated paper insert (immediately preceding Abstract Section) where Mr. Nelson's photographs are printed from extra fine screen engravings for viewing through a stereoscope.

directions. The massing together of the plates has resulted in larger open spaces being formed. This space, of course, has been filled with eutectic in the actual metal. In a few instances, stars can be found; these, however, not as prominent as the samples following.

Many SbSn crystals are found. These crystals are imbedded in the eutectic, clinging to the needles and being penetrated by them. In some instances the cubes are found separating the needles in the bundle. The cubes clinging to the needles are larger than those lying in the eutectic.

Fig. 7* of Sample 3 shows a compact network of CuSn with an abundant amount of stars. Where the angle of incidence of the star is at an oblique angle to the plane of polishing, it is noticed that the star continues into the piece for a considerable distance, extending by means of the needles.

This indicates that the CuSn stars are not merely this shape with but little depth. They are actually of great length and accounts for the many long particles of CuSn seen in the usual examination of a babbitt.

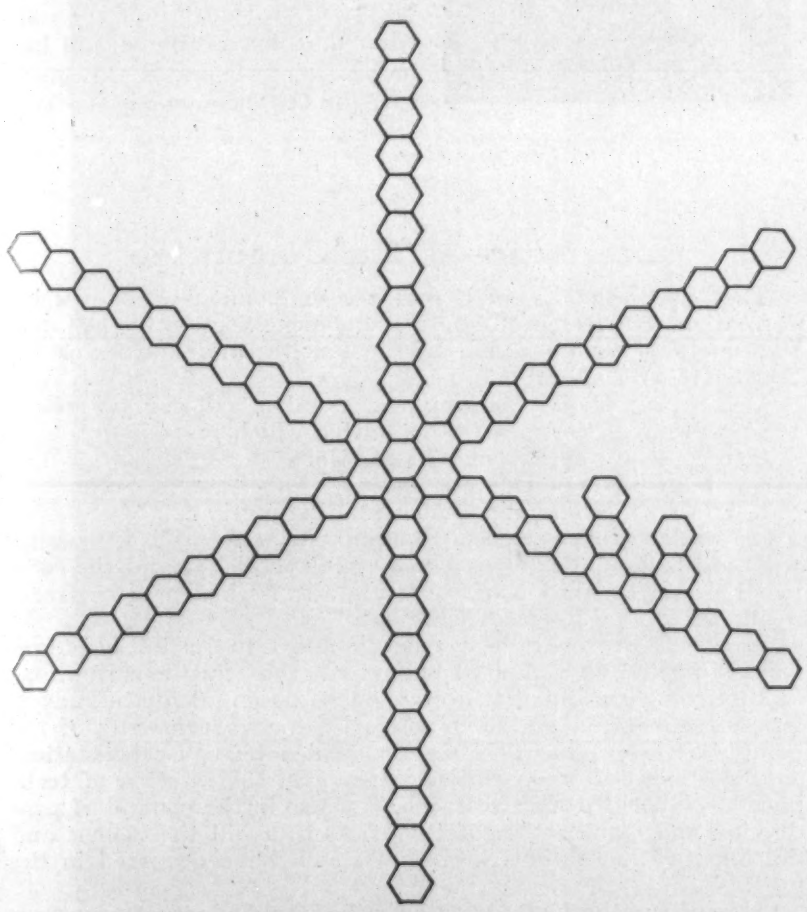


Fig. 3. Diagram of crystallization of CuSn Star.

In this sample, not a particle of SbSn can be found. According to the tin-copper-antimony diagram, this composition is about at the point where the metal will consist of CuSn—eutectic—α solid solution.

Fig. 8* of Sample 4 shows a closely knit matrix of CuSn with many bundles and a large amount of stars. The amount of spaces etched by the acid is very little as compared with the other alloys, indicating a smaller amount of eutectic. The many different phases of CuSn crystallization are very evident with stars penetrating the interior at various angles.

The SbSn crystals are all clinging to the CuSn. They are about twice the diameter and therefore 8 times the volume of the cubes found in the samples containing smaller amounts of copper. They are fewer in number, however, which bears out the theory of Ellis and Karelitz who give as an opinion that the presence of primary CuSn facilitates the early precipitation of SbSn allowing more time for growth.

The foregoing stereoscopic micrographs clearly indicate that the CuSn crystals are of considerable dimensions. Instead of thin plates, small stars, and ringlets, they are of considerable cross section and extend throughout the bearing in the manner of large faggots bundled together. This fits into the fact that the SbSn cubes are trapped by CuSn. SbSn is very light and would undoubtedly rise to the surface with any fine needles or ringlets that would want to cling to it.

The theory of the formation of CuSn is somewhat the same as the formation of a dendrite in other metals. The first spines to precipitate out of solution form the starting point for the growth of the star. These spines settle out in many portions at the same time. Upon further cooling, plates attach themselves to the primary plate on the 6 sides, then continue to attach and grow out into the remaining molten metal. If cooling is slow enough there may be offshoots much in the manner shown in Fig. 3.

These offshoots are always at 60° to the original spine which indicates that CuSn is hexagonal in formation. Examination of a polished and etched surface at high magnification discloses that such is the case. Fig. 2 shows a cross section of a copper tin needle at 1000 magnification. Its distinct hexagonal appearance bears out the previous statement. Many other particles were located with 6 sides but irregular as to dimensions, indicating that the plane of polishing was not at right angle to the length of the spine.

A rough test of the hardness and ductility of the constituents was made by the use of a steel needle hand applied. The eutectic can be easily penetrated and yields easily to pressure. The CuSn needles are very ductile, as shown by their ability to be bent back and forth through a range of 180° several times before breaking. They are easily scratched by the needle. The SbSn cubes are the hardest of all constituents, being very brittle and shattering with pressure by the needle.

A discussion of these results can best be illustrated by referring to the work of Ellis and Karelitz[3] who made exhaustive tests on many babbitts of various compositions. They find that "Compression loads with equal amounts of antimony but with varying amounts of copper show uniform differences in compression. However with the copper content the same and varying the antimony results in less deformation with more antimony. This may be explained by the fact that crystallites of CuSn are in the shape of small needles, while those of SbSn are in the shape of fairly large cubes. Although the needles add greatly to the initial strength of the metal when internal slipping occurs the needles of CuSn are not so effective in preventing further flow as are the cubes of SbSn."

The addition that could be made to the foregoing is that the CuSn is not necessarily in the form of small needles but in the form of rather large bundles of faggots, these bundles being much larger than a single cube of SbSn. They are however much softer and more ductile than SbSn. In the instances where the antimony remains

[3]Ellis & Karelitz. *Transactions American Society of Mechanical Engineers, Machine Shop Practice,* Vol. 50, 1928, page 13.

the same and the copper content varied, the uniform difference in compression can be traced to approximately the same amount of hard antimony tin cubes.

Where the copper remains the same, the samples show less resistance to compression when the antimony content is increased. This is due to an increase in the hard antimony tin cubes.

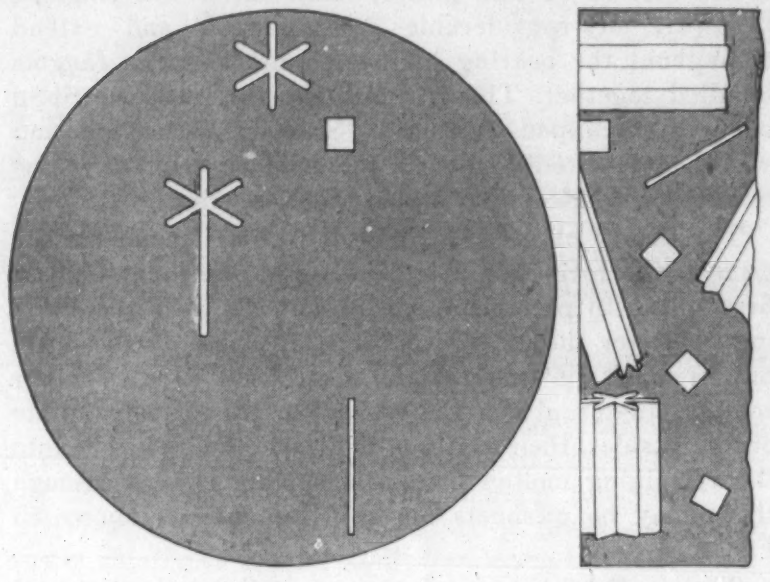


Fig. 4. Diagram illustrating the usual structure as found shown on the left and the position in which they actually are as shown by the projection on the right.

Also "Babbitt may be compared with plastic clay in which are incorporated numerous small splinters and larger cubes of wood. When stress is applied to this clay, both the splinters and cubes help it to resist deformation. At a certain stage of deformation, however, the splinters which initially offered mutual support to one another and thus greatly influenced the strength of the mass as a whole become disturbed and being thus disconnected and relatively small fail to prevent the further deformation of the clay. The larger cubes, however, due to their shape and size still act as keys to inhibit slip."[3] The addition to the foregoing statement is that babbitt may be compared to plastic clay in which are incorporated numerous bundles of faggots and smaller cubes of wood. When stress is applied to this clay, both bundles and cubes help it to resist deformation. At a certain stage in the deformation, however, the faggots, being soft, give with the load and leave the support to the harder cubes.

CONCLUSIONS

1. The CuSn compound is characterized by a hexagonal shaped needle of considerable length. The appearance found on a flat polished sample of long spines, irregular shaped stars, ringlets and small dashes are the out-croppings of the main crystals. Small specks can be classed as CuSn which, due either to a lack of sufficient copper or a drastic cooling has been prevented from assuming normal dimensions.

2. The CuSn compound appears to be the initial crystallization for SbSn. In samples where cubes are clinging to the branches of CuSn, they are larger than those lying in the eutectic areas.

3. Increasing the copper content beyond 6% results in a decreased number of SbSn crystals together with an increase in size of the crystals. If conclusion 2 is a fact this increase in size is due to the greater prevalence of CuSn.

4. In babbitts containing less than 2.5% Cu, the many starting points for crystallization depletes the supply of available copper before the star shaped crystal can form. This results in long spines without the out-croppings necessary to form a star.

5. CuSn is softer and more ductile than SbSn.

6. When 6 pointed stars are found in the specimen, the CuSn crystals are penetrating the matrix for a considerable distance.

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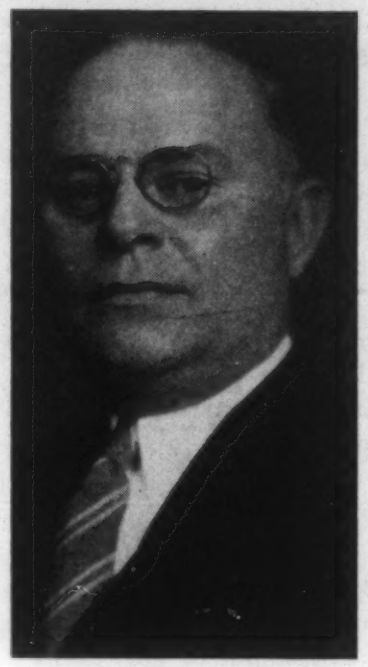

Carl V. Dodge

Carl V. Dodge, manager of roll and steel casting sales of United Engineering & Foundry Company, has been elected a vice president of the company. He has been identified with roll and steel casting production and sales of the company for 26 years.

◈ ◈ ◈

Gear & Forgings, Inc., although in the hands of receivers, contrary to rumors are operating as usual. This is a friendly receivership proceeding and the receivers are operating the company's business under the direction and order of the court that the company may be continued and best interests of Gears & Forgings, Inc., and its customers be conserved.

◈ ◈ ◈

International Tin Committee

The International Tin Committee of London announces the formation of a Research and Development Section to take over the functions and operations of the Tin Research and Industrial Applications Committee.

The Research and Development Section will carry forward the program of the former Committee which is

1. To extend the present uses for tin.
2. To develop new uses.
3. To preserve and strengthen existing markets.

The work includes scientific and industrial research now under way and to be undertaken, commercial publicity, and the compilation and tabulation of statistics, all of which will be freely available to consumers of tin.

The work of research and development in its initial stages was supported on a limited budget by voluntary contributions of tin producers, but it is now financed on an adequate budget, guaranteed over a period of years by the governments of the principal tin producing countries, which have, by legislation, assured their full coöperation not only in the solution of technical problems through research, but also in the control of production and stabilization of tin prices to avoid the violent and detrimental fluctuations in prices which have occurred in the past.

Inasmuch as the United States is the world's largest consumer of tin the benefits of this program to American industries will be of vast importance. The Research and Development Section is organized to coöperate with American tin consuming industries in the solution of problems involving the industrial applications of tin, and it is proposed to carry on much of the research work in this country. An office is maintained in New York City at 149 Broadway, Room 2810, in charge of Mr. L. J. Tavener, in order that the utmost service may be rendered to American tin consuming industries, and to coordinate the Research and Development program with American research activities. Correspondence is invited on all subjects coming within the range of the functions of the Research and Development Section.

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Platinum has come into a new and distinctive use with the striking at the United States Mint in Philadelphia of the first two medals for the Celebration of the Two Hundredth Anniversary of the birth of George Washington. It marks the first time in the history of the Mint that platinum has replaced gold as a medium for outstanding awards.

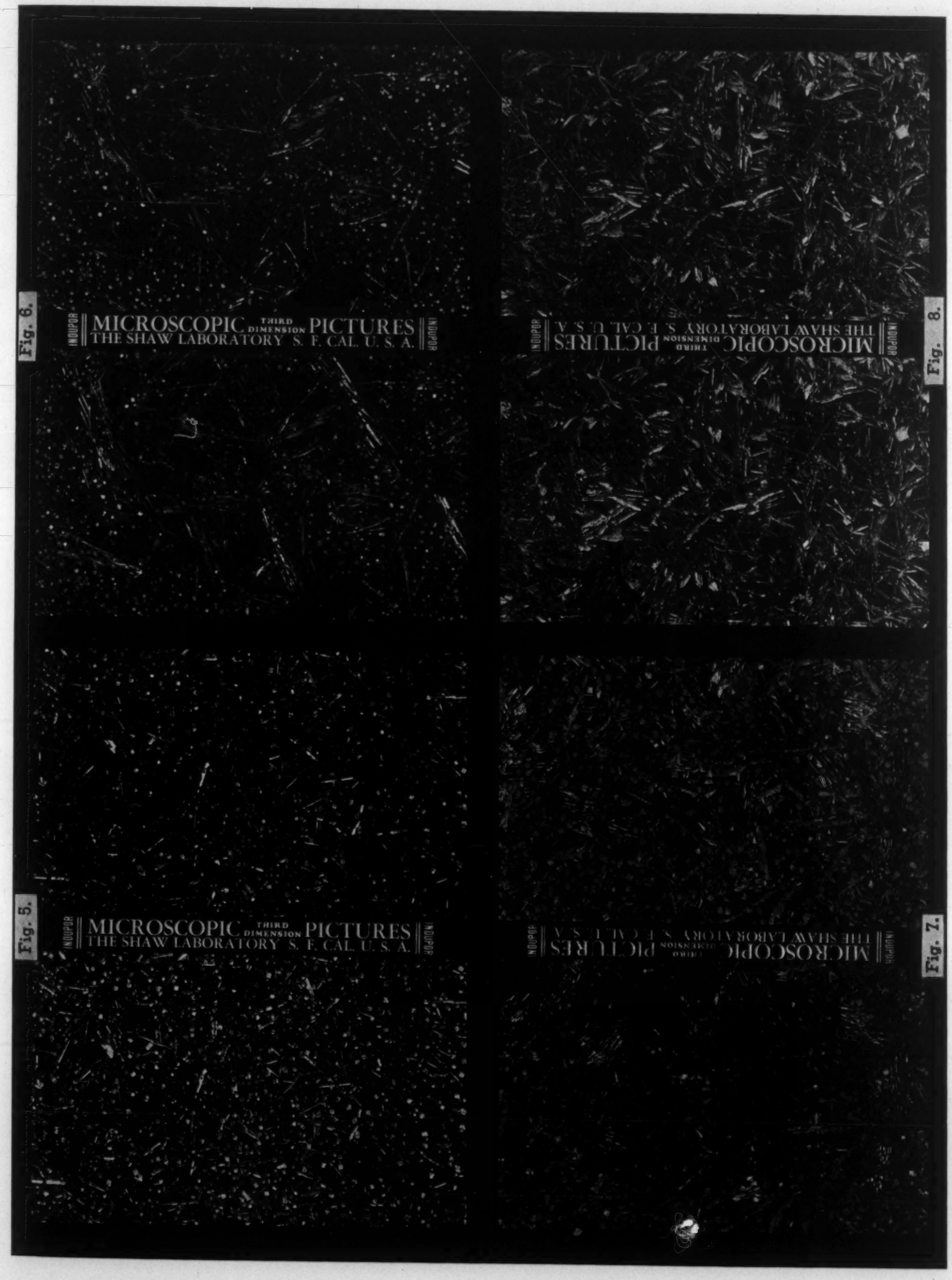

Fig. 5. Stereomicrograph of Sample No. 1, Magnification 25X. SbSn cubes and separate needles of CuSn.

Fig. 6. Sample No. 2, Magnification 25X. SbSn cubes clinging to bundles of CuSn.

Fig. 7. Sample No. 3, Magnification 25X. Bundles of CuSn only, in many sizes and showing large amount of stars.

Fig. 8. Sample No. 4, Magnification 25X. Many bundles and stars of CuSn together with large cubes of SbSn.

CURRENT

METALLURGICAL ABSTRACTS

A digest of the important metallurgical developments of the world

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The readers of METALS & ALLOYS will be interested to know that 2872 abstracts have appeared in this section the six months of this year. As mentioned above the service now covers over 700 publications. An effort is made to have each abstract present the data appearing in the original article. The length of the abstract permits presenting all essential information, as the average number of words per abstract during the last 3 years is 160 words. For most purposes the reading of the abstract can substitute for reading the article.